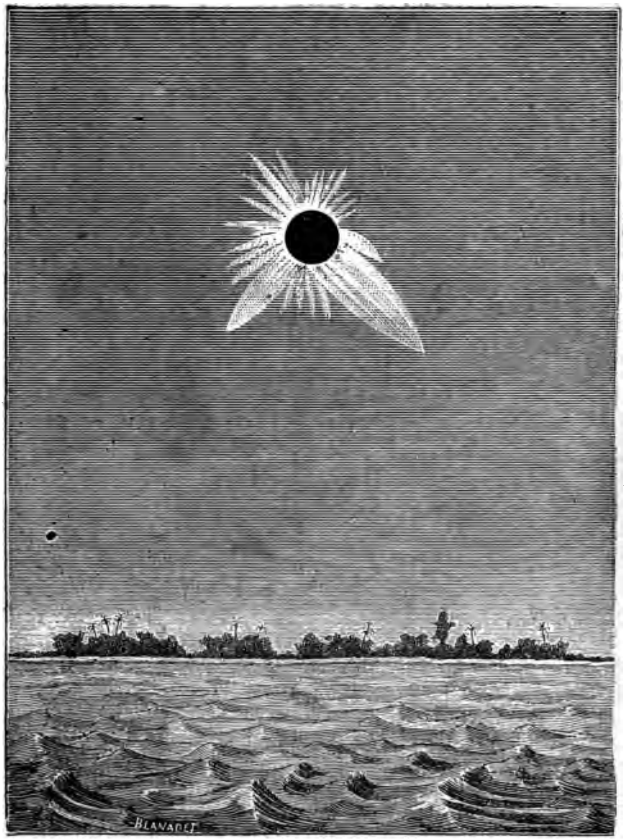
ADVANCED PHYSIOGRAPHY



THE SOLAR CORONA DURING THE ECLIPSE OF MAY 1883.

ADVANCED PHYSIOGRAPHY

BY

JOHN THORNTON, M.A.

HEAD MASTER OF CLARENCE STREET HIGHER GRADE SCHOOL, BOLTON
AUTHOR OF 'ELEMENTARY PHYSIOGRAPHY'

WITH 6 MAPS, 180 ILLUSTRATIONS, AND COLOURED PLATE OF SPECTRA

Jupiter, 1886, from a Photograph

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PREFACE

THIS work may be regarded as a continuation of my treatise on 'Elementary Physiography.' It carries the student into wider realms of nature, and treats of Advanced Physiography as defined by the Syllabus of the Science and Art Department. Whether Physiography be regarded as a separate science or not, it cannot be denied that, as thus set forth, it includes a fairly well-defined and well-ordered series of facts connected with the study of the universe. This is quite as much as can be said of what is included in most of the other 'sciences.'

As will be seen on looking over the contents of the book, many of the marvellous results achieved by what has been called the New Astronomy belong to the course. This department of astronomy is that which has arisen during the last thirty years from the application to the telescope of the spectroscope and the sensitive plate of the photographer. It is concerned more with the physical and chemical constitution of the heavenly bodies than with their exact positions and movements, as discussed in the older department of astronomy. This older branch, however, has not been entirely neglected.

In the preparation of the work I have sought information and help from all available sources—from recent works bearing on the subject, from scientific journals, and from the proceedings of various learned societies. Many specific acknowledgments are made in different parts of the book. Some thirty

illustrations have been specially prepared, while the rest have been obtained chiefly from Ball's 'Elements of Astronomy,' Ganot's 'Physics,' Proctor's 'Old and New Astronomy,' and Schellen's 'Spectrum Analysis.'

I am indebted to my brother, Mr. A. Thornton, B.A., for valuable hints and suggestions in most of the chapters. To the friends who have assisted in the labour of revising proofs I also wish to express my obligations.

In conclusion, the reader is advised to obtain a copy of the excellent pamphlet entitled, 'Demonstrations and Practical Work in Astronomical Physics.' It is issued by the Science and Art Department, and, besides giving an idea of the valuable course of instruction carried on under the direction of Professor Lockyer, will serve as a useful supplement to what is said on this subject in the course of this work.

J. THORNTON.

BOLTON: *February* 26, 1890.

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ADVANCED PHYSIOGRAPHY

CHAPTER I.

THE CELESTIAL SPHERE—CONSTELLATIONS—DEFINITIONS AND EXPLANATIONS.

1. **Introduction.**—An observer situated on the surface of the earth sees above him what he conceives to be a concave surface curving down to the horizon on all sides. This imaginary hemisphere appears to be studded with the various heavenly bodies, and its base, forming the plane by which his view is bounded, is known as the plane of the horizon. As this hemispherical vault is seen at every place on the earth's surface, it is not difficult to arrive at the idea that the earth, which we know to be a globe, is the centre of a vast sphere. Such a conception gives rise to what is generally spoken of as the celestial sphere, and the directions, apparent positions, and motions of the heavenly bodies are defined by referring them to this sphere. During the day the observer appears to see the sun rise in the east above the plane of the horizon—the centre of which he occupies—pass over the concave surface, and disappear at a corresponding point in the west. When this motion is carefully noted day after day in, or near, the middle latitudes of either the northern or southern hemisphere of the earth, the sun's daily path is observed to change, being much larger in summer than in winter. But besides the daily motion of rising and setting, the sun appears to have another motion on the celestial sphere, in a contrary direction when its position is referred to certain other bodies called fixed stars. If at a certain season a particular star, or group of stars, be seen to rise about midnight at, or near, the eastern part of the horizon, at sunrise

or 6 A.M. it will be seen at its highest elevation in the south, and on continuing to observe this group day after day, its elongation from the sun will appear to increase, so that in about three months it will be seen setting in the west as daylight begins. For several months after this it will be invisible just before sunrise, having set previously, but after an interval of about nine months from the first observation, it will appear near the east a little before the sun, and after the lapse of a year the group of stars will again be seen on the meridian as the day dawns. Other stars which rise in or near the east exhibit the same changes, and from this change in the sun's position with respect to such stars, it may be inferred either that the stars have moved towards the west independently of their daily motion, or that the sun has moved eastward among the stars. This eastward motion of the sun is of such a nature, therefore, that in the course of a year it is found to have made a complete circuit of the star sphere, its annual path being known as the *ecliptic.* ('El. Phys.' 297 and 303.)

The fixed stars are those celestial objects that constantly keep the same position with respect to each other, and are by far the most numerous of the objects seen in the heavens. Many are visible to the naked eye every clear evening after the sun has set, and some of them, like the sun, appear to rise from below the plane of the horizon, and after a longer or shorter journey they again disappear below it. But, unlike the sun, they rise again time after time exactly at the same points of the horizon as before. Other bodies of this class never reach the horizon, but seem to move in a circular path round a fixed point in the heavens. This point is called the pole of the heavens, and is very near a well-known star called the Pole star. In fact, after watching the fixed stars for a few days, the whole celestial sphere seems to revolve round an axis daily, the end of this axis being at a certain height above the horizon depending on the latitude of the observer; and the axis itself passes through the position he occupies to a point below his horizon. During this revolution all the fixed stars move together, and keep the same distance from each other, just as if the celestial sphere were solid and they were set in it, so that

in the course of the day the stars appear to describe circles of different sizes, the centres of which are at the pole. If the observer change his station on the earth by travelling northward, he notices that the axis becomes more and more perpendicular to his horizon, while if he travel southward the angle of its inclination becomes smaller; but in whatever position he may be the stars are seen to move over parallel circles on the visible concave in the same period of time. In the last chapter of our 'Elementary Physiography' there is an account of the apparent daily motion of these fixed stars, when the spectator is supposed to be at the Pole, the Equator, and at an intermediate latitude. At the Pole the diurnal circles are seen to be parallel to the horizon, at the Equator the circles are vertical, while in mid-latitudes the circles are oblique to the horizon. In each case, however, the axis about which the sphere of stars is seen to revolve passes through the earth perpendicular to the planes of the circular paths apparently described by them. The student will also carefully note that, however much we change our station on the earth, and so alter our horizon, the angular distances between the stars do not alter. This can only be accounted for by conceiving the whole earth to be a mere point compared with the distances of the stars.

Besides the fixed stars there are several other bodies very similar in appearance to the naked eye, but possessing apparent motions differing greatly from those of the fixed stars. Though they rise and set daily, yet they do not keep the same relative positions among the other stars. Sometimes they seem, when watched for several days, to move among the fixed stars in the same direction as the sun; at other times they seem to be going in an opposite direction, while they occasionally appear to be stationary. Hence these bodies have been called planets (Gr. *planetes*, a wanderer). Five of them, now called Mercury, Venus, Mars, Jupiter, and Saturn, have been noticed for thousands of years. These planets are not only distinguished from the fixed stars by their more complex movements, but also by showing, when seen through a telescope, a distinct circular disc, or portion of such disc, the size of which increases with the magnifying power of the instrument, while the fixed

stars appear as mere points of light.[1] As we shall afterwards learn, these planetary discs are due to their comparative nearness to us, all the fixed stars being at vastly greater distances than any of the planets.

The moon also appears to have two very distinct motions, a daily motion of rising and setting, and an eastward motion among the fixed stars. If we notice the new moon, which appears as a crescent-shaped body just after sunset, before its light becomes bright enough to shut out that of the stars near it, its place among them may be distinctly seen. On the following night at the same hour it will seem to have been left behind by the stars, and to have sensibly increased its distance from them to the east. It will also be noticed that the moon rises, reaches its highest point, and sets from half an hour to an hour later each night, and that during its revolution it presents to us a number of different appearances, or phases, dependent on its position in relation to the sun. Its motion, in fact, is of such a nature that after the space of time we call a month it again occupies the same position with respect to the sun. Thus the sun, moon, and planets, in addition to their daily apparent motion, have separate motions of their own, which cause them to change their places among those glittering points known as fixed stars; but these fixed stars, known to be at vast distances from the earth, show no movement beyond that produced by the earth's diurnal motion, and, keeping the same relative positions year after year, form a class of celestial bodies quite distinct from the other bodies of the universe.

These are some of the phenomena which every intelligent observer has noticed while gazing at the heavens. But these motions are in general only apparent, and can be properly explained by referring them to a combination of various other motions. As we have proved in the last chapter of the 'Elementary Physiography,' with the facts of which the reader is assumed to be acquainted, the apparent diurnal rising and setting of the heavenly bodies is due to a real daily rotation of

[1] The image of a point of light like a star is a small disc surrounded by bright rings. This *spurious disc*, as it is called, is quite distinct from a planetary disc, and diminishes in size as the diameter of the object-glass of *the telescope is increased.*

the earth on its axis, while the varying lengths of day and night, the apparent eastward motion of the sun in the ecliptic, and the whole of the phenomena connected with the seasons have been shown to be due to this daily rotation in conjunction with a yearly revolution round the sun, during which the earth's axis of rotation maintains a constant angle of inclination to the plane of its orbit. The phenomena are the same, however, whether we suppose the earth to be at rest, and the starry sphere to turn daily, and the sun to revolve yearly, or whether we conceive of the motions as we really know them to exist.

2. **The Celestial Sphere.**—It is usual in astronomy to regard the celestial sphere as of such dimensions that, on whatever

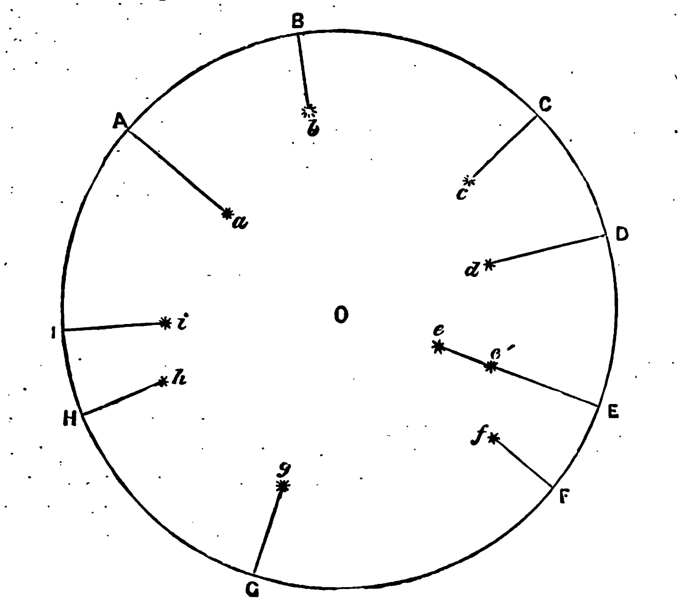

FIG. 1.—Section of the imaginary Celestial Sphere.
The observer at O, looking at the celestial bodies *a*, *b*, *c*, *d*, *e*, *e'*, *f*, *g*, *h*, *i*, sees them projected along straight lines, so that their apparent places on the distant surface of the sphere are A, B, C, D, E, F, G, H, I.

part of the earth the observer may be at any time, he is practically at the exact centre. The apparent positions of the heavenly bodies are thus seen to be points on the sphere where

the lines drawn from the eye through the objects intersect the sphere. The apparent place of an object thus depends on its direction only, irrespective of its distance. Fig. 1 will illustrate this.

3. **Dimensions on the Celestial Sphere.**—Apparent distances and dimensions on the celestial sphere are not expressed in miles or other linear units, but in angular units. The common angular unit is the right angle. This is subdivided into degrees, minutes, and seconds.[1] But there is another angular unit that is sometimes employed, called a *radian*. A radian is the angle at the centre of a circle subtended by an arc equal in length to the radius of the circle. All radians are equal, and the magnitude of an angle may be expressed by the number of radians to which it is equal. This number is called the *circular measure* of the angle. Knowing that the circumference of a circle is 3·14159 times the diameter, we see that the arc of a semicircle which subtends an angle of 180° is 3·14159 times the radius. Dividing 180 by 3·14159 we see that a radian is equal to 57·3°, or 206265″ nearly. If we speak of an angle whose circular measure is 2·7, we mean 2·7 radians. To express

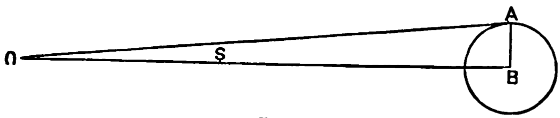

FIG. 2.

it in degrees we multiply 57·3° by 2·7. Thus we see how to pass from circular measure to rectangular measure, and *vice versâ*. Not only may we speak of angular distances and dimensions as measured on arcs of the celestial sphere, but we may also speak of angular velocity, meaning the angle, either in degrees or radians, moved through in a certain unit of time. Thus we say that the angular velocity about the earth's axis is the same for all stars, as we know that they move through their own circles of rotation in the same time. What has just been said will enable us to show the relation that exists between

[1] It will be useful for the reader to remember that the apparent diameter of the sun or moon is about half a degree, or 30′; that the distance between the pointers of the Great Bear is about 5°; that the distance between the nearer pointer and the pole star is about 30°; and that the distance from the point overhead to the horizon is 90°.

the apparent size and the linear distance of an object. Let A B represent the apparent semi-diameter of a distant object as seen from the point O. Knowing the angle *s* at O and the length of O A, we can determine the length of A B when the ratio of the length of A B to the distance O A is very small. Suppose a large circle to be described from O as centre through the point A or B, then the length of the chord of the small angle *s* will be practically the same as the length of the arc of the circle passing through these points. Now the angles subtended at the centre of a circle by arcs of its circumference are proportional to the lengths of those arcs, therefore A B must bear the same ratio to the distance O A that the angle *s* bears to the angle subtended by an arc equal to the radius O A. This latter angle is according to definition an angle of one radian, or 206265″. Hence we have the proportion A B : O A :: *s* : 206265. In the case of the moon O A is 239,000 miles, and the angle *s* is about 15′ 3″. This gives the moon's semi-diameter as 1,076 miles. Knowing then that the angle subtended at the centre of a circle by an arc equal to the radius contains 206,265″, and that other angles are proportional to the arcs on which they stand (which arcs in the case of small angles may be taken as equal to the chord or straight line joining the extremities of the arc), we have the following:—

$$\begin{matrix}\text{Semi-diameter} \\ \text{of a body in miles}\end{matrix} : \begin{matrix}\text{the distance} \\ \text{in miles}\end{matrix} :: \begin{matrix}\text{the angular} \\ \text{semi-diameter} \\ \text{in seconds}\end{matrix} : 206265'',$$

or, calling the semi-diameter R and the distance D,

$$R = \frac{D \times \text{angular semi-diameter in seconds}}{206{,}265}.$$

If in fig. 2 we suppose O to be the centre of the sun or moon, and A B a radius of the earth, the lines O A and O B may be regarded as radii of the large circle described from centre O through these points. The small angle *s* is thus the angle which the semi-diameter of the earth subtends at the sun, and if we know its value, then we see from the above that

$$D = \frac{206{,}265 \times R}{\text{angle } s \text{ in seconds}}$$

that is, *the distance* of a heavenly body is equal to 206,265

times the radius of the earth divided by the number of seconds in the angle which this base-line subtends at the heavenly body. The distance D may also be obtained when we know R and s, since the angle at A is a right angle, from the relation, $\sin s = \frac{AB}{OA}$ This gives the distance OA or $OB = R \div \sin s$.[1]

4. **Diurnal Rotation of the Star Sphere.**—*The Fixed Stars.*—As we shall have to refer so often to the fixed stars it is advisable to make a few more remarks on these bodies before going further.

By the aid of fig. 3, remembering that the eye of the

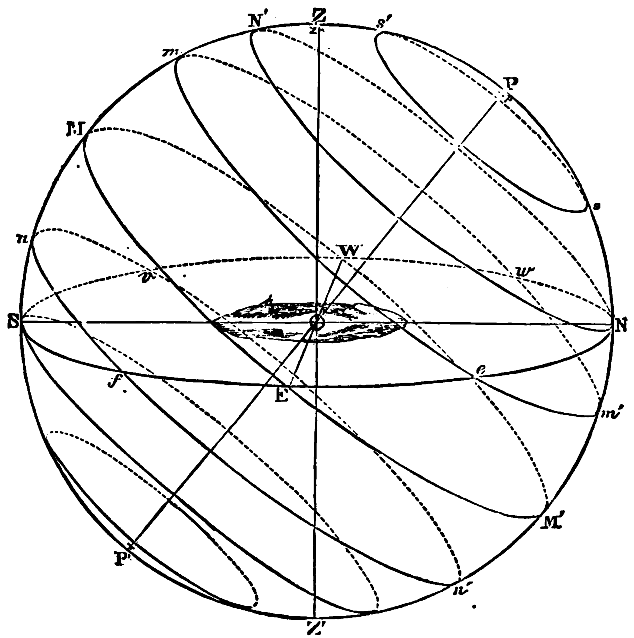

FIG. 3.—The Celestial Sphere.

observer is regarded as being at the centre of the sphere, we may represent the daily rotation of the celestial sphere as it is

[1] A short explanation of some of the terms used in trigonometry will be found in the Appendix.

observed in the latitude of London. An observer at O in the latitude of London sees above him the hemispherical dome represented in the upper half of fig. 3, E S W N representing the plane of his horizon extended so as to cut the celestial sphere at these points, Z represents the spectator's zenith, and Z′ his nadir in the hemisphere below the horizon. The line P P′, passing through the observer's position O, is the axis round which the celestial sphere seems to turn. A star rising at E, midway between the north and south points of the horizon, ascends at a uniform rate in about six hours to its highest point or culmination M, on the arc S Z, passes thence in the same time to W, where it sets, only to rise again at E the next day. If a star rises at *f* its diurnal course above the horizon is smaller, and the time during which it is visible is shorter. It culminates at *n*. Stars rising anywhere on the arc E N culminate somewhere on the arc between M and N′, remain above the horizon more than twelve hours, and set just as far to the west of the north point as they rose to the east of it. Other stars passing from a point on the arc N P make a complete circuit every day above the horizon around the pole P, and these stars, the whole of whose diurnal circle is performed above the horizon, are known as *circumpolar stars*. We cannot follow the course of the stars during the whole of their daily journey with the naked eye owing to the bright light of the sun overpowering their light in the daytime, but by keeping up our watch every clear night in the year we may see them in all parts of their course, and with a powerful telescope, properly set up as afterwards described, the daily rotation of many of the stars can be followed throughout the whole course. Whatever be the course described by any star, it must be noted that its apparent motion is quite uniform, the complete circuits, whether long or short, being all performed in the same time, due to the equable rotation of the earth on its axis.

5. **Time of Rotation of the Star Sphere.**—If we carefully note the exact time at which a star rises, or at which it occupies a certain position in the sky, we shall find that it comes to the same position in the sky a little earlier on the following evening. Hence, if a telescope be pointed to a star, and the exact time at which the star passes the central wire be noted, the telescope having been left fixed in its position, the same star will arrive again on the central wire in 23 h. 56 min. 4 sec. of solar time. This interval,

during which the star-sphere performs one complete revolution, is really the time in which the axial rotation of the earth is performed, and is called a sidereal day (par. 300, 'Elementary Physiography'). Owing to the earth's annual motion in its orbit round the sun, it takes the earth a little longer to come into two successive similar positions relative to the sun than for two relative to the same fixed star. As a consequence of this difference in length between the sidereal day and the mean solar day used for reckoning civil time, we easily understand that, by looking at the sky night after night, we see a continuation of the same kind of change that is observed during the progress of any one night. In the course of about fifteen days the stars seen in a certain position at any given hour at the beginning of this period will be about 15° to the west, having advanced westward one hour's motion. In about a month they will be two hours' motion further west; in six months the attitude of the earth with respect to the stars at midnight is the same as it was at noon six months previously; at the end of a year they will have made a complete revolution—in fact, the star sphere will have made 366 revolutions in 365 days. Bearing this in mind, we shall know what changes to expect in the positions of the stars as the year progresses. A star, or group of stars, that rises in the east and is seen in the south at ten o'clock P.M. at the beginning of December, will have to be looked for in the S.S.W. about the middle of January at the same hour. Other stars will have made a corresponding advance—an advance equal to that made in their circle of daily rotation in about three hours.

6. **Magnitude and Number of Fixed Stars.**—One of the most marked features of the fixed stars is their different degree of brightness. The word 'magnitude' is used in this connection to denote the different orders of stars. Twenty of the brightest stars are said to be of the first magnitude. Of these Sirius is the brightest of all. Next in order come stars of the second magnitude, of which there are about sixty-five. Following these we have stars of the third magnitude, stars of the fourth magnitude, and so on. Few people can detect stars beyond the sixth magnitude with the naked eye; but the telescope reveals stars so faint that they are spoken of as being of the sixteenth magnitude. The total number of stars visible to the naked eye is about 6,000, and, as we can only see one-half of the sky at once, the greatest number visible at any one time on a clear night is about 3,000. But, by the aid of the most powerful telescopes, the number visible exceeds 50,000,000. Even this number is greatly increased by the aid of photography, as rays of light from stars, too faint even to be seen in the telescope, can by long exposure of a sensitive chemical film make their existence evident. It is worthy of note that the number of stars of each magnitude increases as their brightness becomes

fainter, there being as many as 142,000 stars of the ninth magnitude, while from the first to the sixth magnitude there are only about 6,000.

7. **Constellations.**—Another feature of the fixed stars, that seems to have impressed itself on the minds of the ancients, is the resemblance to the figures of animals and other objects, that are supposed to be formed by the groups of stars in the various parts of the heavens. Many of these figures are absurdly fanciful, yet the astronomer has found it convenient to retain the names of these groups in order to mark out the different regions of the heavens. These artificial groups are spoken of as *constellations.* Thus we speak of the constellation Ursa Major (the Great Bear), Corona Borealis (the Northern Crown), Cancer (the Crab), Cassiopeia, Orion, &c. The stars of each constellation are distinguished by the letters of the Greek alphabet, the brightest star of each constellation having the letter α (alpha) prefixed, the next brightest has the letter β (beta), the next brightest γ (gamma), and so on to the end of the alphabet. For the sake of those unacquainted with the Greek, the letters of this alphabet with their names are given in the Appendix.

When the Greek alphabet has been exhausted, the other stars of a constellation have Latin letters or a number prefixed. Besides the above mode of distinguishing stars, all the brightest stars are known by special names (some of which are said to be of Arabic origin,) as Aldebaran, Vega, Arcturus, Sirius, &c. In this way many stars have two names: thus, α Tauri (Aldebaran); α Ursæ Minoris (Polaris); γ Pegasi (Algenib), &c. In addition to the above methods, which would fail for the thousands of smaller stars, catalogues of stars have been published, and it is customary to refer to them by the number in the catalogue. Thus there are the catalogues of Argelander, of Lalande, the British Association Catalogue, and numerous others. The reference 4,356 B.A.C. or 19,746 Ll. refers to the stars so numbered in their respective lists, where information about the position of these stars will be obtained. The names and relative positions of the chief constellations may be learnt by a few nights' observation of the heavens at different parts of the year, if the learner will seek the aid of a celestial globe or a good star-atlas. A few hints are all that can be given here. The reader will bear in mind from what has been previously said that the positions occupied by the constellations at stated hours will vary during each month of the year. The position of the Pole star may be ascertained after recognising the constellation of Ursa Major or the Plough, the seven principal stars of which may be seen in the northern part of the sky on any clear night. Two stars of this group are known as the 'Pointers,' as they always point very nearly to the Pole star. If the reader look for it at nine o'clock on any clear night, he will see it in various *positions depending on* the time of the year, and if he continue his

observation for a few nights, its movement round the pole of the heavens will be very apparent. Thus, in January and February he will see it to the east of north with the Pointers highest, but at the same hour in April and May it will be north of the zenith. In three months more it will be to the west of north, with the Pointers lowest, while in October and November it is seen at this hour just above the northern horizon. Polaris

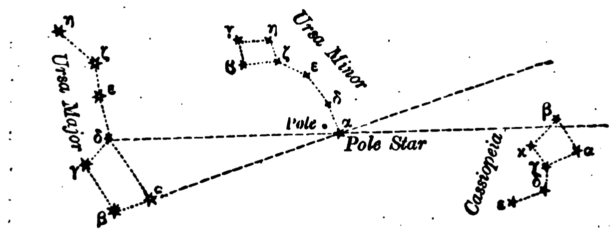

FIG. 4.

(the Pole star) is a star of the second magnitude, and is the brightest star in the constellation Ursa Minor. It is situated at present at a distance of about $1\frac{1}{4}°$ from the pole of the celestial sphere, the true pole being at the centre of the small circle described by the Pole star.

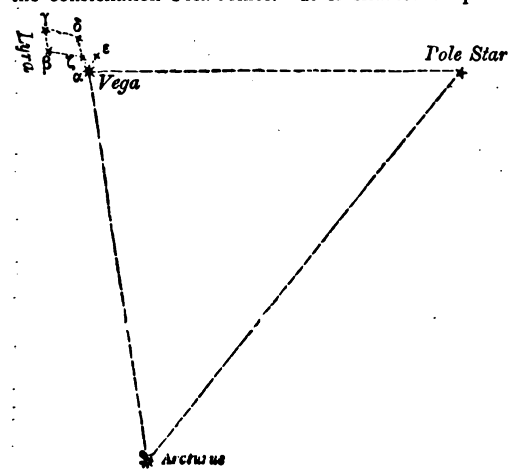

FIG. 5.

On the side of the Pole star opposite to Ursa Major is another well-known group of circumpolar stars, five of which form something like a W. This constellation is known as Cassiopeia. Other circumpolar constellations lying within the area of fig. 4, but not shown, are Cepheus, Draco (the Dragon), and Camelopard. They may be found by comparing a star-map with the heavens. A line drawn from the Pole star through β of Cassiopeia and produced as far again reaches Alpheratz in Andromeda, one of a large square. This star only sets for a short time. The three other stars of the square belong to the constellation Pegasus.

Another line drawn through the last two stars in the tail of Ursa Major passes about 30° south of them through Arcturus, α Bootis. This is the *brightest star in the* northern hemisphere. Vega (α Lyræ) is the second

brightest star, and may be recognised as the vertex of a large right-angled triangle formed on the line joining Polaris and Arcturus. The brightest star in the constellation Perseus is of the second magnitude, and forms the central star of a curve called the arc of Perseus. A line drawn from α Andromedæ through β and γ of the same constellation terminates near α Persei. The three stars of Perseus that form the arc will be seen from the figure. On producing this arc it passes through a star of the first magnitude called Capella, in the constellation Auriga. On the convex side of the arc lies the remarkable star, β Persei, known as Algol, while not far from this lies a well-known cluster of stars called the Pleiades. To the left of this group lies another cluster of stars called the Hyades, in which is seen a first-magnitude star of ruddy hue known as Aldebaran (α Tauri). From Aldebaran the fine constellation of Orion is easily found to the south-east. This constellation when at its highest point is seen about 40° above the horizon in our latitudes. This occurs in the middle of December about midnight, in the middle of January about ten o'clock P.M., in the middle of February about eight o'clock P.M., and so on through the year. The contour of Orion is marked by four bright stars, forming an irregular quadrilateral, the two brightest, Betelgeuse (α Orionis) and Rigel (β Orionis), being respectively at the north-east and south-west corners. Near the centre of the quadrilateral are three stars that form the belt of

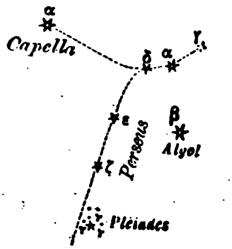

FIG. 6.

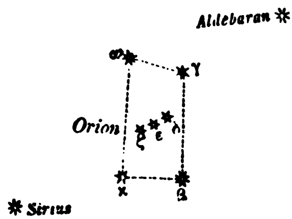

FIG. 7.

Orion; these point upwards to Aldebaran, already mentioned, and downwards to the brightest star in the heavens, Sirius. This, with a few other stars of small magnitude, forms the constellation of Canis Major. Procyon (α Canis Minoris), another first magnitude star, is about 25° east of Betelgeuse, and forms with Sirius and Betelgeuse almost an equilateral triangle. With these few hints and the help of a celestial globe or a star-atlas, the student may gradually become acquainted with the chief constellations and their principal stars. A planisphere is also very helpful in learning the relative positions of the stars, and in finding their positions on the concave sphere at a given hour on each day of the month. When using a celestial globe the reader must remember that we are looking at the stars from the outside of it, whereas we are really situated at the centre. Consequently the position of the stars is reversed, so that of two stars, for example, the one that is to left of the other on the celestial globe will be seen to the right on looking at the heavens. Before using the globe it must be rectified. Its axis must be made parallel with the axis of the earth by elevating the Pole to correspond with the latitude of the place, by seeing that the brass meridian is in a true north and south direction, and by making the wooden horizon *truly horizontal.* Then on turning it on the poles of the equator

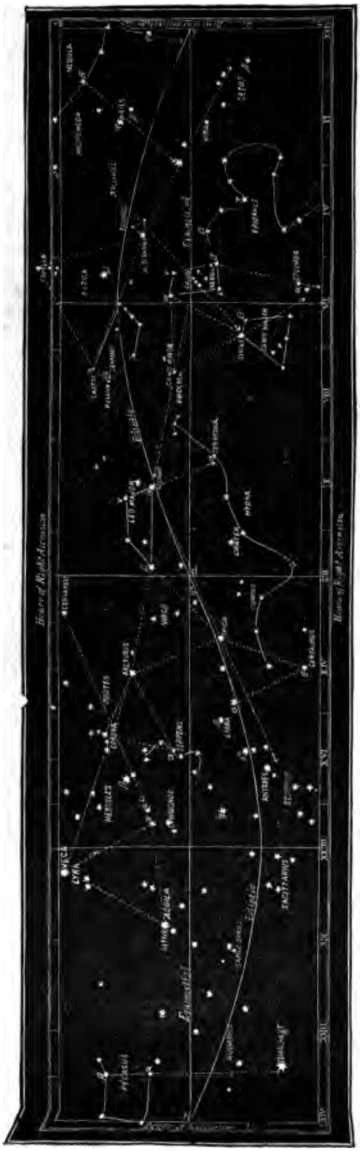

Fig. 8.—Showing the positions of the principle Constellations and Stars between the Declinations of 40° N. and 40° S.

from east to west we shall represent the apparent daily rotation of the heavenly bodies, and shall easily see what portion of the diurnal circle of any star is above the horizon and what portion below it. In star-maps the position of the stars is laid down as we actually see them from the earth. Fig. 8 is a star-map showing a zone or belt of the celestial sphere 40° on each side of the equator, spread out on a flat surface. It is reduced from one given in Jeans's 'Handbook of the Stars.' The dotted lines are merely lines of direction to help in finding the relative positions of the various stars.

8. **The Sphere.** — A sphere is a body whose surface is such that every point upon it is equidistant from a point in the interior called the centre. It may be regarded as generated by the revolution of a circle about its diameter. The diameter about which it turns is called its axis, and the ends of the axis are the poles of the sphere. All the radii of a sphere are equal, and a diameter is twice a radius. If a section be made by a plane passing through the centre, it cuts the surface of the sphere in a circle, which is called a *great circle*. Any number of great circles may be supposed to be drawn on the surface of a

sphere, and any two will bisect each other. Thus in fig. 3 S E N W and M E M'W and P M'P'M are three great circles of the celestial sphere, each pair bisecting one another—the first pair at E and W. All great circles of a sphere are equal, and the terms 'primary' and 'secondary' are names given to any two great circles of a sphere whose planes are at right angles to each other. The *poles of a circle* are those two points in which a straight line perpendicular to its plane at the centre intersects the sphere. Any section of a sphere made by a plane which does not pass through the centre cuts the surface of a sphere in what is called a *small circle.* The distance between two points on the surface of a sphere is the length of the arc of the great circle passing through them, and is usually measured by the angle which the arc subtends at the centre of the sphere, so that the angle is often called the *angular distance* between the extremities of the arc. Distance on the arc of a great circle is the shortest distance between any two points on the surface of a sphere.

A *spherical angle* is the angle made by two great circles, and may be expressed by the planes of the two great circles. If three points, A B C, be taken on the surface of a sphere, then the arcs of the three great circles that pass through them form a *spherical triangle.* In the spherical triangle A B C, fig. 9, the arcs A B, B C, C A are measured by the angles A O B, B O C, C O A. The angles formed by the intersection of the arcs are also the angles contained by the planes A O B, B O C, C O A. Thus the spherical triangle has six parts, but all the six quantities involved in its consideration are angular magnitudes, a side of a spherical triangle being the angle formed at the centre of a sphere by two straight lines of a solid angle, and the angle of a spherical triangle being the angle made by the two planes of a solid angle. Any two sides of a spherical triangle are greater than the third side, and the sum of the three sides is always less than 360°. In a plane

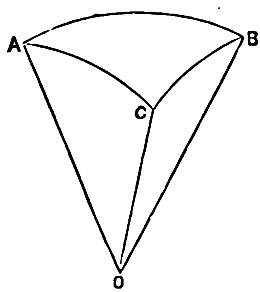

FIG. 9.

triangle the three angles are together equal to two right angles, but in a spherical triangle the three angles always exceed 180° but are less than 540°.

9. **How to Define the Position of the Stars.**—In speaking of the *position* of a heavenly body we do not now refer to its actual position in space, to define which we must know its distance measured in miles from the earth, but of its position on the concave surface of the heavens, in reference to certain fixed points on imaginary great circles, and measured by arcs of such circles. There are three systems of great circles on the celestial sphere, sometimes spoken of as spherical rectangular co-ordinates, as each system consists of two great circles of the sphere at right angles to each other. These may be called the Horizontal System, the Equinoctial System, and the Ecliptic System. The first of these with reference to the *horizon* will now be described, but as this changes from hour to hour and from place to place, other methods will also be needed which will be of use at any station and at any time. It will be seen that the last two methods fulfil this requirement.

10. **First Method of Defining the Position of a Heavenly Body.**—*Altitude and Azimuth.*—As already mentioned, it is often useful to describe the position occupied by a celestial body at a given place and at a given time. In this system the objects are referred to the horizon as the fundamental plane, and in the northern hemisphere the south point of the horizon is the point of origin. The *astronomical* or *rational horizon* is a great circle of the celestial sphere, the plane of which passes through the centre of the earth. The *physical* or *sensible horizon* is the circle of the celestial sphere the plane of which passes through the observer. But at the immense distance of the celestial sphere these two parallel planes pass into one great circle, the horizon as defined above.[1] The *zenith* is the

[1] The word *horizon* is also used to denote the boundary line where the sky appears to meet the land or sea. This boundary line is often called the *visible horizon*. If the spectator's eye be supposed at the water-level, the horizon would be the great circle of the heavens whose plane touches the earth at the position of the spectator; but if the observer's eye be elevated above the surface of the earth, the visible horizon is a small circle depressed below this great circle. The amount of this depression is called the *dip of the horizon*. In the fig. D A is the height of the observer measured on the line passing through the earth's centre, E; A F the horizontal line from A; and A B a tangent to the earth's surface. The horizontal circle passing through B would mark out the visible horizon. The angle F A B is the dip of the horizon, and A B its distance. By Euclid III. 36 it can be shown that

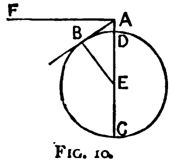

FIG. 10.

point of the celestial sphere directly overhead, or the point where a plumb-line produced upward would meet the sky. It is thus determined at each place by the direction of gravity. The *nadir* is the point of the celestial sphere directly under foot opposite the zenith. Thus the zenith and the nadir are the poles of the horizon. *Vertical circles* are great circles which pass through the zenith and the nadir, and are therefore perpendicular to the horizon.

Parallels of altitude are small circles parallel to the horizon.

The *prime vertical* is the vertical circle that passes through the east and west points of the horizon.

The *celestial meridian* is the great circle passing through the zenith and the poles of the celestial sphere. Its intersection with the horizon marks the north and south points of the horizon, and its plane is perpendicular to the plane of the prime vertical.

The *altitude* of a heavenly body is its elevation above the horizon measured on the arc of the vertical circle passing through the body. It may also be measured by the angle which this arc subtends at the centre of the horizon. (See fig. 11.)

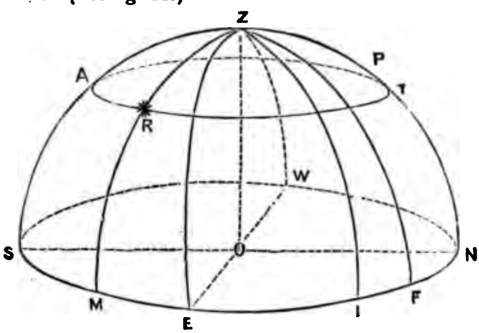

FIG. 11.—The Horizon and Vertical Circles.

O, the observer's position.
Z, the zenith. P, the pole.
S E N W, the horizon.
S Z P N, the meridian.
E Z W, the prime vertical.
M Z, I Z, F Z, arcs of other vertical circles.
R, a star's position.
A R T, a parallel of altitude.
Z R M, arc of star's vertical circle.
Arc S M, or angle S Z M, star's azimuth.
Arc M R, or angle subtended by it at O, star's altitude.
Arc R Z, star's zenith distance.

The *zenith distance* of a body is its angular distance from the zenith, and is therefore the complement of the altitude. Altitude + zenith distance = 90°.

As a star approaches the meridian its zenith distance diminishes, and a star attains its greatest altitude on the meridian, when it is said to *culminate*. When a star has reached the meridian one half of its visible path

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the distance of the visible horizon in miles is equal to the square root of the height of the eye in feet added to its half.

$$\text{Distance (in miles)} = \sqrt{\tfrac{3}{2} h} \text{ (in feet)}.$$

Also, Dip (in minutes of arc) $= \sqrt{h}$ (in feet).

is accomplished, and the passage of a heavenly body over the meridian is called its *transit*. A circumpolar star—*i.e.* one whose whole diurnal circle is above the horizon—has an upper and a lower culmination, and the half sum of these two altitudes gives the latitude of the place.

The *azimuth* of a body is the arc of the horizon intercepted between the south point of the horizon and the foot of the vertical circle passing through the body. It may also be defined as the angle at the zenith between the celestial meridian and the vertical circle passing through the body.

The *amplitude* of a heavenly body is the angular distance of its rising point from the east and of its setting point from the west, measured along the horizon, or measured by the angle which this arc subtends at the observer's position in the centre of the horizon. The amplitude of the fixed stars remains the same throughout the year, but the sun's amplitude varies during the year. It is nothing at the equinoxes, and about 40° at the solstices for our latitude. Most of the foregoing definitions are illustrated by the annexed figure.

As an illustration of the use of these terms we may be required to point out the position of a star whose azimuth is 60° and whose altitude is 45°. Reckoning from the south point eastward, as usual in the northern hemisphere, we proceed two-thirds of the distance towards the east for its azimuth, and then look up half-way to the zenith. An object in the north-west, by reckoning again from the south point through the east, will have an azimuth of 225°, and one in the south-west an azimuth of 315°. A star on the line Z S has azimuth 0°, and all stars on Z N have azimuth 180°. If we require to find a star whose azimuth is 270° and altitude 60°, we locate it on the arc Z W at a distance of two-thirds from the horizon, or one-third from the zenith, as its zenith distance must be 30°.

11. **Second Method of Defining the Position of a Heavenly Body.**—*Declination and Right Ascension.*—By referring the places of the heavenly bodies to the Celestial Equator as the fundamental plane instead of the horizon, we obtain elements independent of the observer's position, and, as far as the fixed stars are concerned, independent of the time (except a very small change to be explained hereafter).

The *celestial poles* are the points where the earth's axis of rotation, prolonged indefinitely, would meet the celestial sphere. Any line from a point on the earth at any part of its orbit, *parallel to this axis*, vanishes at the same points at the infinite distance of this sphere. The *celestial equator* or *equinoctial* is the great circle of the celestial sphere 90° from each celestial pole. It may also be regarded as the great circle in which the plane of the earth's equator cuts the celestial sphere. At its highest point it is just as far below the zenith as the pole is above the horizon, and it cuts the horizon at the east and west points.

The *declination* of a heavenly body is its distance from the Equator measured on the arc of a great circle passing through the body and the pole. It is reckoned positive (+) north of the Equator and negative (−) south of it. *Circles of declination* are great circles passing through the poles of the heavens, and consequently at right angles to the Equator. They are better called *hour circles*, and correspond to the meridians of the earth. But these celestial meridians must not be confused with *the* meridian already defined. *Parallels of declination* are small circles parallel to the celestial equator.

The *hour angle* of a star is the angle at the pole between *the* meridian and the hour circle passing through the star. It is often expressed in hours,

minutes, and seconds of time, one hour being equal to 15°, and one minute and second of time being respectively equal to 15′ and 15″ of arc. In consequence of the earth's daily rotation, the hour angle of a star varies at a uniform rate. It expresses the time which the star will need to reach the meridian if on the east side of it, and the time that has passed since it crossed the meridian if on the west side of it.

The *polar distance* of a star is the arc of the hour circle between the star and the pole. Declination + polar distance = 90°. (See fig. 12.)

The *right ascension* of a star is the arc of the equator intercepted between a certain point of the equator called 'the first point of Aries' and the star's hour circle; or, by taking the equivalent of this arc, right ascension may be defined as the angle at the pole between the star's hour circle and the hour circle passing through the first point of Aries. It is always reckoned towards the east, through a whole circumference if necessary; and, as it is usually expressed in time, it may be of any magnitude from 0 h. to 24 h. Right ascension is commonly abbreviated thus, R.A.

The *first point of Aries* is that point on the equator where the sun crosses it in spring. As already explained in the 'Elementary Physiography,' par. 300, the ecliptic is the great circle in which the plane of the earth's yearly orbit round the sun cuts the celestial sphere. This great circle is inclined to the celestial equator, the angle between the ecliptic and the equator being spoken of as the *obliquity of the ecliptic*. This angle has a value of about 23° 27′. It is in consequence of the inclination of these two great circles to each other that the ecliptic cuts the equator or equinoctial line in two opposite points; the point where the two cut when the sun passes from north to south is called the *first point of Aries*, or the Vernal Equinox, while the other point of intersection is called the *first point of Libra*, or Autumnal Equinox. The hour circle passing through these two points is called the *Equinoctial Colure*. The solstitial points are the two opposite points of the ecliptic which are 90° distant from each of the equinoctial points, and the hour circle passing through them is called the *Solstitial Colure*. On June 21 the sun is at the summer solstice, and about December 21 at the winter solstice. ('El. Phys.' 306.) Like other fixed points of the heavens the points above mentioned partake of the daily rotation of the sky, and transit the meridian at different times, depending on the period of the year.

Sidereal time depends on the position in the sky of the vernal equinox, and may be defined as 'the number of sidereal hours, minutes, &c., since the last preceding transit of the first point of Aries.' As already explained, a sidereal day is the interval between two consecutive meridian passages of any one star, and this, owing to the sun's eastward motion among the stars consequent on the earth's yearly revolution, is a shorter interval than that between two consecutive meridian passages of the centre of the sun. Hence a sidereal day is nearly four minutes shorter than a solar day, its exact length being 23 h. 56 m. 3·6 s. of mean solar time. Thus there are 366¼ sidereal days in the year, and only 365¼ solar days. The sidereal day is considered to begin when the first point of Aries is on the meridian of the place of observation, and the sidereal clock, keeping sidereal time, is so adjusted as to indicate twenty-four hours for the interval between two successive transits of this point—*i.e.* during one complete rotation of the earth. (An ordinary clock keeps mean solar time.) Hence the beginning of the sidereal day does not correspond to any particular hour of mean time, but

during the year it passes through all the hours of the civil day.[1] The sidereal clock marks 0 h. 0 m. 0 s. when the vernal equinox is on the meridian of the observer, two o'clock when the hour angle of the vernal equinox has moved owing to the earth's rotation through 30°, twenty-one o'clock when it has moved through 315°. We thus see that the sidereal time at any instant is equal to the distance expressed in time of the first point of Aries westward of the meridian, which is also equal to the R.A. of the point of the celestial sphere then passing the meridian. As the R.A. of the first point of Aries is 0°, the R.A. of a star when given in time always expresses the sidereal time of its passage over the meridian.

By means of the annexed figure most of the definitions in the two preceding paragraphs receive illustration.

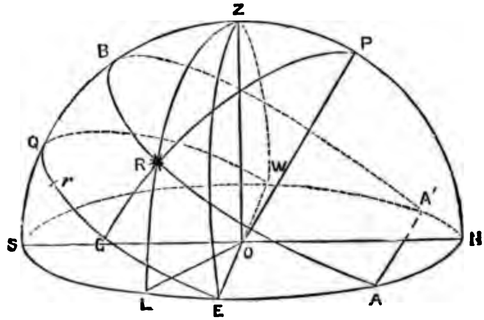

FIG. 12.

O, observer's position.
S E N W, the horizon.
Z, zenith. P, pole.
R, position of a star when observed.
A B A', position of star's diurnal circle.
E Q W, the equator.
O P, the polar axis.
S Z P N, the meridian. P G, hour circle.
L R Z, arc of star's vertical circle.
E Z W, prime vertical.
L R, star's altitude.
Z R, star's zenith distance.
Angle S Z L, or arc S L, star's azimuth.
r, first point of Aries.
Arc G R, star's declination.
Arc R P, star's north polar distance.
Angle R P S, star's hour angle.
Arc *r* G, star's right ascension.

12. **Third Method of Defining the Position of a Heavenly Body.**—*Celestial Latitude and Longitude.*—This is the method often used in referring to the position of the planets. The student will have noticed already that the terms declination and right ascension correspond to the terms latitude and longitude used in speaking of the position of places on the earth's surface, as in both cases the equator of the sphere in question is the primitive circle by which the above elements are measured. But in speaking of celestial latitude and longitude it must be carefully noted that the ecliptic is the circle of origin.

[1] The first point of Aries comes on the meridian about noon on March 22. Next day, however, this point transits nearly four minutes before the sun; on March 29, $7 \times 4 = 28$ minutes before the sun. In this way the approximate sidereal time at mean noon on any date may be obtained. On September 21 it is about 12 h. sidereal time at noon.

Celestial latitude is the angular distance of a body from the ecliptic measured on the arc of the great circle passing through the body and the pole of the ecliptic.

Celestial longitude is the arc of the ecliptic between the vernal equinox and the circle of celestial latitude passing through the place of the heavenly body. It is always measured eastward through a whole circumference of 360°.

The latitude and longitude of a heavenly body therefore bear to the ecliptic the same relations which the declination and right ascension bear to the equator. By means of trigonometrical calculation the one set of co-ordinates can be easily converted into the other. The annexed figure shows the relation between the two methods of defining the positions of objects in reference to the two fixed circles of the celestial sphere.

The reader should endeavour to trace out in the sky the paths of the equator, ecliptic, and other imaginary circles. The equator occupies a fixed position in the heavens, and may be traced by fixing three of its points,

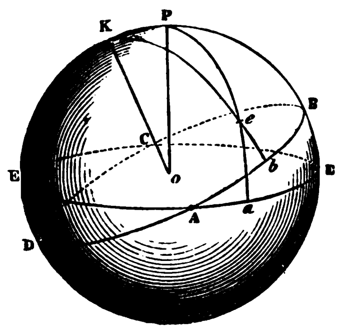

FIG. 13.

o, observer.
A B C D, ecliptic.
A E C F, equator.
K, pole of ecliptic.
P, pole of equator.
A, first point of Aries.
C, first point of Libra.
e, position of a star.
A *a*, right ascension of star.
e a, declination of star.
A *b*, longitude of star.
b e, latitude of star.
Angle B A E, obliquity of ecliptic, or its inclination to the equator.

the east point, the west point, and a point in the south, at a distance from the zenith equal to the latitude. It is 90° from the pole, one half being above the horizon, the other half below towards the north, all parts of it rising daily in the east and setting in the west. At the equinoxes it is traced out by the daily path of the sun on those two days. The path of the ecliptic is not so readily imagined, as it is constantly shifting, different parts of it being on the meridian at noon or midnight at different parts of the year. The sun's yearly path is on the ecliptic, and the motions of the planets take place nearly in the same great circle. It can be most easily found at night by learning the conspicuous stars that are near it. (See fig. 8.)

13. **The Zodiac.**—The zodiac is a zone or belt of the celestial sphere, *extending about 8°* on each side of the ecliptic. It was

so called because the constellations within this region are often represented on celestial charts and globes by the imaginary figures of animals (Gr. *zodion*, an animal). Within this zone the apparent motions of the sun, moon, and all the greater planets are confined. The ecliptic passes through the centre of the zodiac, and, like it, is bisected by the equator. The zodiac, like the ecliptic, is divided into twelve equal parts of 30° each called *signs*, and these are designated by the names of the constellations with the places of which they once corresponded. They are: Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, and Pisces. These signs are counted from the vernal equinox, where the sun intersects the equator at the beginning of spring in the northern hemisphere. Owing to a slow backward movement of the equinoctial points, to be afterwards explained, the sun now enters the *sign* Aries about a month before it enters the *constellation* Aries. Hence the signs of the ecliptic are about one place ahead of the corresponding constellations of the zodiac, and on this account it is necessary to distinguish between the *signs* of the zodiac and the *constellations* of the zodiac, which keep a fixed place on the celestial sphere. Appended is a list of the signs with their symbols and the meaning of their Latin names, the first six being those north of the equator and the last six those south of it.

The northern signs, with their distance from the vernal equinox or first point of Aries, are:—

1.	♈	Aries (the ram)	0° to 30°.
2.	♉	Taurus (the bull)	30° to 60°.
3.	♊	Gemini (the twins)	60° to 90°.
4.	♋	Cancer (the crab)	90° to 120°.
5.	♌	Leo (the lion)	120° to 150°.
6.	♍	Virgo (the virgin)	150° to 180°.

The southern signs are:—

7.	♎	Libra (the balance)	180° to 210°.
8.	♏	Scorpio (the scorpion)	210° to 240°.
9.	♐	Sagittarius (the archer)	240° to 270°.
10.	♑	Capricornus (the goat)	270° to 300°.
11.	♒	Aquarius (the waterman)	300° to 330°.
12.	♓	Pisces (the fishes)	330° to 360°.

The sun enters the sign Aries at the time of the vernal

equinox, March 22, and about a month later it enters the second sign, Taurus, and so on. On June 21 it will have attained its greatest northern declination, $23\frac{1}{2}°$ N., and its right ascension will be about 90°, or, expressed in time, six hours. Three months later, when its daily motion is on the equator, its declination will be zero and its R.A. 180°, or twelve hours. Thus, a little consideration will enable the student to give approximately the declination and R.A. of the sun on any day of the year. The exact value of these co-ordinates will be

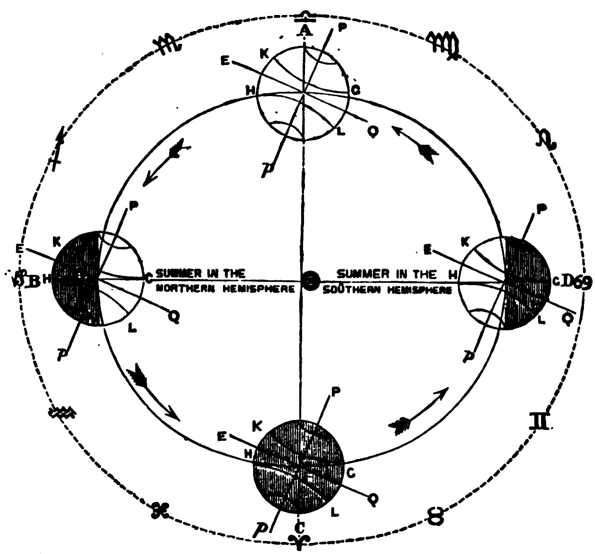

FIG. 14.

found on the first page of each month in the 'Nautical Almanac.' The sun's yearly motion through the fixed stars in the signs of the zodiac is illustrated in fig. 14. This motion is a result of the earth's yearly motion in its orbit. When the earth is at A the sun appears projected on the distant celestial sphere in the sign Aries, ♈ ; a month later it has begun to enter the sign Taurus, ♉ ; after a lapse of another month it is at the beginning of the sign Gemini; and when the earth is at B the sun appears in the sign Cancer, and so on. Thus the sun always appears

to be in the opposite point of the heavens to that of the earth, and separated from it by 180° of longitude. It appears to describe a yearly circuit among the stars, its eastward advance or motion in right ascension being caused by the onward motion of the earth in its orbit, and its varying mid-day height, or motion in declination, being due to the fact that the plane of the terrestrial equator extended to the heavens cuts the plane of the earth's annual orbit at two opposite points, forming with it an angle of $23\frac{1}{2}$°. The two points where the celestial equator and the ecliptic intersect are the equinoctial points; and when the earth is at these points the plane of the terrestrial equator meets the sun, so that the circle of illumination just reaches from pole to pole. When the earth is at other points of its orbit, the circle of illumination reaches beyond one pole, and falls short of the other by an amount varying up to $23\frac{1}{2}$°. The two points in the ecliptic midway between the equinoxes are called the *Solstices*, because the sun there stands still in declination, and begins to move towards the equator again. Two circles drawn through the solstices parallel to the celestial equator are known as the *Tropics*. A full account of the phenomena of the seasons is given in the Elementary Physiography.

CHAPTER II.

GENERAL SURVEY OF THE SOLAR SYSTEM.

14. **Meaning of Solar System.**—The solar system consists of the sun and all those heavenly bodies whose motions are controlled by its gravitation, viz. the planets with their satellites, the comets, and certain of the bodies called meteors. As it was Copernicus who first showed that the sun is really the centre round which the planets revolve, and that the earth itself is a planet with a daily rotation on its axis, and a yearly motion round the sun with its axis constantly parallel, the system is sometimes spoken of as the Copernican system. But it was Newton who was the first to *explain* all these celestial motions *by the law of* universal gravitation, the centre of gravity of the

whole system, and not the sun's centre, being the real point round which the planets revolve. Owing to the enormously preponderating mass of the sun, this point is, however, at a comparatively small distance from the sun's centre. He also proved mathematically that the orbits or paths of the planets are ellipses with the sun occupying one focus. In the more ancient systems of astronomy, such as that of Ptolemy, the earth was regarded as fixed in the centre, and the heavenly bodies were looked upon as set in a number of surrounding transparent crystalline spheres. In the outermost sphere were set the fixed stars, while each of the seven planets had its own transparent sphere; the sun, then regarded as a planet, being supposed to revolve between Venus and Mars. The rolling of these crystal spheres produced a refined 'music of the spheres' heard only by immortal ears. To account for the apparent motions of some of the planets, they were supposed to move in a small circle, or *epicycle*, the centre of which was carried uniformly along the circumference of a large circle, the centre of which was occupied by the earth. But the need for these epicycles of Ptolemy disappeared when the sun came to be looked upon as the centre of the planetary motions.

15. **Members of the Solar System.**—The following celestial bodies constitute the solar system:—(1) The enormous body called the Sun situated near the centre. (2) Eight large planets arranged as follows, in the order of distance from the sun, the first being the nearest, viz.: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune. A ninth planet called Vulcan has been suspected to revolve nearer to the sun than Mercury, but no satisfactory proof of its existence has been given. Each of these primary planets, except Mercury and Venus, has one or more *satellites* or *moons* revolving round it and accompanying it in its revolution round the sun. (3) A number of small planets or planetoids revolving at various distances between the orbits of Mars and Jupiter. Up to the end of 1889 the number of these minor planets known was 287. Ceres, Pallas, Juno, and Vesta were the first to be discovered. (4) An unknown number of comets, bodies which move round the sun in orbits of extremely elongated form and

of almost all degrees of inclination to the ecliptic. Many of them exhibit the well-known nucleus and tail when sufficiently near to be visible. (5) A vast number of meteors, bodies travelling, for the most part, in swarms over elliptic orbits and closely associated with the comets. Some of these passing through our atmosphere are seen as falling stars. Before describing the various members of the solar system in detail we propose in this chapter to take a general view, and to point out certain relations among the various members.

16. **Orbits of the Planets.**—The planets are dark globular bodies shining like the earth by reflected sunlight, and revolving at various distances round the sun in elliptical orbits, of which the sun occupies one focus. But the elliptical shape of a planet's path is often exaggerated in diagrams, as the exact figure of a planet's orbit on paper could not be distinguished by the eye from a circle. When nearest the sun the planet is said to be in *perihelion*, and when at the point of its orbit most remote from the sun it is said to be in *aphelion*. All the planets travel round the sun in the same direction, and this direction, when we look upon the system from the northern side, is from right to left, or in a direction opposite to the hands of a watch. This eastward motion is spoken of as *direct*, motion in the opposite direction being spoken of as *retrograde*. All the planets revolve on their axes in the same direction, and thus give rise to the phenomena of day and night, but the inclinations of the equatorial planes to the plane of the ecliptic vary We know that in the case of the earth the axis of rotation is inclined at an angle of $23\frac{1}{2}°$ from the perpendicular to the plane of the ecliptic—*i.e.* the plane of the equator and the plane of the ecliptic form this angle at their intersection, and on this inclination our seasons greatly depend. The axial inclination of the other planets is referred to in par. 24.

17. **The Ellipse.**—To understand the terms used in describing the planetary motions it is advisable to know some of the properties of the figure called an ellipse. A method of describing such a figure is explained in 'El. Phys.' par. 300. An ellipse may be defined as *a closed curve such that the sum of the two distances from any point on its circumference to the two points within called the foci is always constant, and equal to the major axis of the ellipse.* Thus in fig. 15, S and H are the foci, C the centre, *AA'* the major axis, and BB' the minor axis. $SL + LH = SB + BH =$

A A′. A C or A′C is the semi-major axis, and is equal to S B, which is called the mean distance, being the mean between A S, the least, and A′S, the greatest distance from S. A is the *perihelion* of a planet's orbit round the sun, or the *perigee* of the moon's orbit round the earth, while A′ in a similar manner is either the aphelion or apogee. A, A′, the two extremities of the major axis, where the revolving body is moving at right angles to the straight line joining it with the primary, are called the *apses* or *apsides*, and the line passing through these points and indefinitely produced in both directions is called the *line of apsides*. The *eccentricity* of the orbit is the

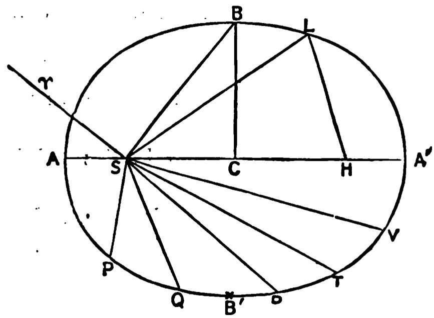

FIG. 15.

ratio of S C to A C, and may be represented by the fraction $\frac{SC}{AC}$; in other words it is the proportion which the distance of the focus from the centre bears to the semi-major axis or mean distance. Suppose S C = 2, and A C = 3, the eccentricity of the orbit = $\frac{2}{3}$ or ·6. The more nearly an ellipse approaches a circle the smaller the fraction representing the eccentricity. The sign ♈ indicates the direction of the first point of Aries, and the angle ♈ S A is the longitude of perihelion. P being the position of a planet at a certain time, the angle ♈ S P is the longitude of the planet, while the angular distance of a planet as seen from the sun, viz. the angle A S P, is called its *anomaly*. The time taken by a planet or satellite to move through its whole orbit is called its *period* or *periodic time*. The *ellipticity* of the spheroid which the ellipse would generate by revolving round one of its axes is the proportion which the difference of the two axes bears to the greater of them; it is therefore represented by the fraction which the difference of the two axes is of the major axis.

18. Common Characteristics of the Planets.

(1) All the planets travel round the sun in the same direction, and their course, when viewed from the north side of the ecliptic, is from right to left, or opposite to the motion of the hands of a watch. This kind of motion is called *direct*,

while motion in the contrary direction, from left to right, is spoken of as *retrograde.*

(2) All the planets describe elliptical orbits of small eccentricity with the sun in one focus—that is, their orbits are nearly circular.

(3) The orbits of all the planets are *nearly* in one plane (with the exception of some of the minor planets or asteroids); but as each of them has a different but small inclination to the plane of the earth's orbit, each one intersects the ecliptic in two points, which are the *nodes* of the planet's orbit, so that one half of each orbit lies north of the earth's path and one half south.

(4) All the planets are globular bodies shining like the earth by reflected sunlight.

(5) All the planets rotate on their axes, and the direction of rotation, as far as is known, is the same as that of their orbital revolution.

(6) All the planets, in accordance with the principles of gravitation, move with the greatest velocity when in perihelion, and with the least velocity in aphelion.

19. **Distances of the Planets from the Sun.**—The planets perform their journey round the sun at very various distances, and, remembering that the orbits are somewhat elliptical, we see that they are sometimes more distant than at others. The following figures may be taken for the approximate mean or average distances from the central luminary. We also give the periodic time of each planet, from which it will be seen that the nearer a planet is to the sun, the greater is its velocity in its orbit. These comparative velocities form the third column of the table.

	Mean Distance in Millions of Miles	Period of Revolution round the Sun in mean Solar Days	Orbit Velocity in Miles per Second
Mercury .	36	87·97	23 to 35
Venus .	67·2	224·7	21·9
Earth . .	92·9	365·25	18·5
Mars . .	141·5	686·9	15
Jupiter .	483·5	4332·6	8
Saturn .	886·5	10759·2	6
Uranus .	1782	30688	4·2
Neptune .	2792	60181	3·4

The following figure will give some idea of the relations among the different members of the solar system, but the student will easily see from

the foregoing numbers that the distances are not drawn to scale, because it is not possible to represent by one figure the real proportions of the orbits in any book of convenient size, Neptune being eighty times as far distant from the sun as Mercury. Later on we shall show these real proportions in certain cases.

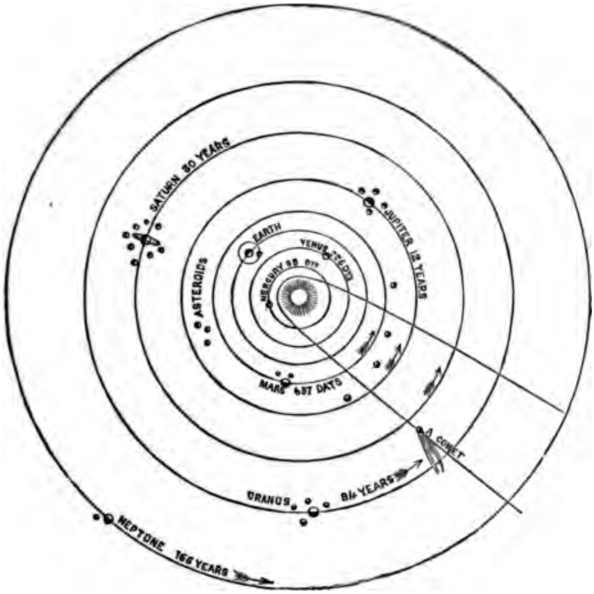

FIG. 16.

20. **Bode's Law.**—Each planet, it will be noticed, is about double the distance of the preceding one from the sun, and this curious relation between the distances of the planets from the sun is known as Bode's Law. It may be represented as follows. Write down nine 4's for the nine planets, counting the minor planets between Mars and Jupiter as one. To the second 4 add 3; to the third add 3×2; to the fourth add 3×4; to the fifth 3×8; and so on, doubling the number added each time.

$$4,\ 4+3,\ 4+6,\ 4+12,\ 4+24,\ 4+48,\ 4+96,\ 4+192,\ 4+384.$$

Divide the resulting numbers by 10, and we get the following numbers, which represent approximately the planetary distances (except that of Neptune), calling that of the earth unity.

Mercury	Venus	Earth	Mars	Mi. Pl.	Jupiter	Saturn	Uranus	Neptune
·4	·7	1	1·6	2·8	5·2	10	19·6	38·8

No explanation has been given of this strange relation, and it may be due to mere coincidence.

21. Comparative Sizes and Masses of the Planets.—The subjoined figures supply information which will help the reader to some idea as to the relative sizes and masses in planets.

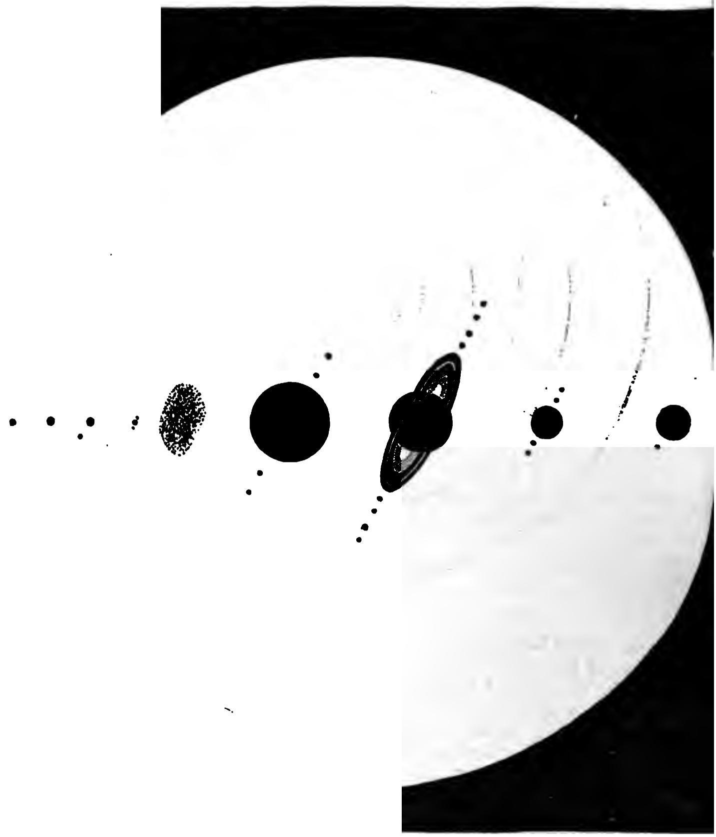

FIG. 19.—The Sun and his family of Planets, with their Satellites.

From the diameter we can obtain the volume by multiplying the cube of the diameter by $\frac{11}{21}$, and, knowing the volume and the mass or quantity of matter in each, we can readily obtain the density or comparative weight ('El. Phys.' 14, 22). Before

reading the table the following figure from Proctor's 'Old and New Astronomy' will furnish to the eye some means of realising the relative sizes of the members of the solar system. The white disc represents the sun, and the black discs the planets arranged across this disc in the order of their distances from the sun, starting on the left with Mercury, while the very small dots are used to indicate the minor planets or asteroids between Mars and Jupiter.

	Diameter in Miles	Mass (Earth being 1)	Density compared with Water
Mercury .	3,030	$\frac{1}{8}$	12·4
Venus . .	7,700	$\frac{4}{5}$	4·8
Earth . .	7,918	1	5·5
Mars . .	4,220	$\frac{1}{9}$	4·0
Jupiter .	86,000	316	1·3
Saturn .	71,000	94	·72
Uranus .	31,800	14·7	1·22
Neptune .	34,500	17·1	1·1
Sun . .	866,400	331,100	1·4

It will be seen from the above table that, although the diameter of the sun (regarding the disc that we see as the sun) is $109\frac{1}{2}$ times greater than that of the earth (its volume being therefore nearly 1,310,000 times as great), yet the quantity of matter it contains is but 331,100 times as great. Even taking all the planets together, the sun exceeds them in mass some 750 times. It may be noticed also that Saturn is the least dense of all the planets, and that there is, roughly speaking, a progressive increase of density passing from him in both directions.

To assist the reader to realise the comparative magnitude of the sun, and the relative distances of the planets, the following table, based on Sir John Herschel's illustration of the solar system, is added.

	Representative Object	Representative Radius of Planet's Orbit
Sun	Globe of 2 feet radius	
Mercury	Grain of mustard seed	164 feet
Venus	A pea	284 feet
Earth	A pea	430 feet
Mars	A rather large pin's head	654 feet
Minor Planets	Small grains of sand	1,000 to 1,200 feet
Jupiter	A moderate sized orange	2,227 feet, or $\frac{1}{2}$ mile
Saturn	A small orange	4,083 feet, or $\frac{3}{4}$ mile
Uranus	A full-sized cherry	8,212 feet, or $1\frac{1}{2}$ miles
Neptune	A small plum	12,864 feet, or $2\frac{1}{2}$ miles

On the same scale the nearest fixed star would be at a distance of 8,000 miles, which shows that the solar system is a mere isolated group in the universe.

22. **Classification of the Planets.**—The planets have been divided into primary, minor primary (called also planetoids or asteroids), and secondary. The primary planets are Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. These are subdivided into inferior and superior planets. Mercury and Venus are called *inferior* planets because their orbits are included within the orbit of the earth, while the others, whose orbits lie beyond that of the earth, are spoken of as *superior* planets. The minor planets, or asteroids, consist of a number of small bodies moving between the orbits of Mars and Jupiter. The first of these was discovered by a Sicilian astronomer on January 1, 1801. He called it Ceres. Next year another was found and named Pallas; Juno, the third, was discovered in 1804; and in 1807 Vesta, the largest and brightest of the group, was seen. For a time discovery of these bodies ceased, but since 1845 almost every year has added to the number, so that at the beginning of 1890, 287 of these bodies had been catalogued. The inclination of their orbits to the plane of the ecliptic averages about 6°, but many of them exceed this considerably, that of Pallas being 35°. In size they vary from Vesta, whose diameter has been estimated at about 300 miles, to bodies of about five miles in radius. The secondary planets are satellites or moons revolving round a primary planet, and accompanying it in its revolution round the sun. Twenty such bodies are now known. Of these the Earth has one, Mars two, Jupiter four, Saturn eight, Uranus four, and Neptune one.

Humboldt divided the primary planets into two groups, which he called *terrestrial* planets and *major* planets. The terrestrial planets are Mercury, Venus, the Earth, and Mars. Speaking broadly, these have much in common in their physical constitution. Water and an atmosphere possibly exist on all, and, leaving out Mercury, which probably exceeds considerably the average density of the other three, their density is nearly the same. The major planets are Jupiter, Saturn, Uranus, and Neptune. These are much larger bodies than the terrestrial planets and have a much smaller density, and appear to present to us only a cloudy surface. Three of them, moreover, are the centres of a complex system of their own.

23. **Inclination of Planetary Orbits to the Ecliptic-Nodes.**—*The plane* of the ecliptic is that plane passing through

the earth's orbit extended to the celestial sphere. The orbits of several of the larger planets lie very nearly in the same plane, while the orbits of many of the comets cut this plane at angles varying to 90°. The amount of this inclination for each planet may be thus given; the more exact figures will be found in the table in the Appendix:—Mercury, 7°; Venus, 3° 23′; Mars, 1° 51′; Jupiter, 1° 18′; Saturn, 2° 30′; Uranus, 0° 46′; Neptune, 1° 47′. The two points in which the orbit of a planet or another celestial body intersect the plane of the earth's orbit are called its *nodes*, while the line joining these points is called the *line of nodes*. The *node* at which the planet passes to the north side of the ecliptic is called the *ascending node*, and the node at which the body passes to the south of the ecliptic is called the *descending node*.

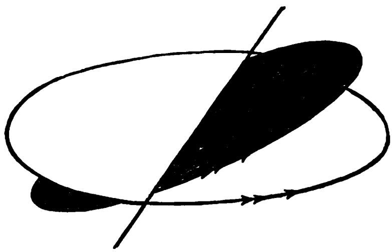

FIG. 18.—Inclination of two Orbits and Line of Nodes.

24. **Inclination of the Equatorial Planes of the Planets to their Orbits.**—We have seen in the 'Elementary Physiography' that the plane of the earth's equator is inclined to the plane of the ecliptic at an angle of 23½°, and that the inclination of these two planes in conjunction with the annual revolution of the earth gives rise to the phenomena of the seasons. This inclination of the plane of a planet's equator to the plane of its orbit—or what is in reality the same, the inclination of the planet's axis from the perpendicular to this plane—has been determined satisfactorily for three of the other planets—Mars, Jupiter, and Saturn. In the case of Mars the inclination is nearly 24° 50′, very little more than that of the earth; in the case of Jupiter this inclination is only about 3°, while the inclination of the axis of Saturn to its orbit is 28°. These figures show that Mars and Saturn will have seasonal differences somewhat more pronounced than those of the earth in so far as seasons depend on this circumstance, and that Jupiter will be a planet almost without seasons.

25. **Elements of a Planet's Orbit.**—The elements of a planet's orbit are certain numerical quantities that are necessary to be known in order to give an exact description of its orbit, and in order to compute the position of the planet at any given time, past or future.

These elements are six in number:—

1. The semi-major axis of the orbit, or the mean distance.
2. The eccentricity of the orbit.
3. The inclination of the plane of the orbit to that of the ecliptic.
4. The longitude of the ascending node.
5. The longitude of perihelion.
6. The epoch, or the place of a planet in its orbit at a particularly fixed time.

The first two of these elements determine the size and form of the orbit, the next two fix the position of the plane of the orbit in space, while the fifth and sixth elements determine the position of the orbit with regard to he sun, and enable the astronomer to ascertain at what part of its orbit a planet is at any moment.[1]

26. **Kepler's Laws.**—The celebrated German astronomer Kepler (1571–1630) enunciated three laws which govern the motions of the planets. They are as follows:—

(1) The planets revolve in elliptical orbits, having the sun in one of their foci.

(2) The radius vector of each planet describes equal areas in equal times.

(3) The squares of the periodic times of the planets are in proportion to the cubes of their mean distances from the sun.

These laws are only close approximations to the truth. They would be perfectly accurate if the masses of the planets were inappreciably small. But, if the masses be taken into account, the gravitational effects of the planets on each other and the sun produce slight deviations. These deviations, however, can be accurately determined and accounted for. Though the orbits, therefore, are not perfect ellipses, they are very nearly so, and the focus of the orbit of any planet is more

[1] As shown in a book the orbit of a planet is usually laid down on a plane surface. 'Incline it slightly as compared to some fixed plane ring, and the element of inclination (as regards its amount) will present itself. (The astronomical fixed plane in this case is that of the ecliptic.) Imagine a planet following the inclined ellipse; at some point it must rise above the level of the fixed plane: the point at which it begins to do so, measured angularly from some settled starting-point, gives the *longitude of the ascending node*. Then the planet's position in the ellipse when it comes closest to the principal focus gives us when projected on the plane-ring the place of nearest approach to the focus—in other words, the *longitude of perihelion*' (Chambers). Refer to figs. 15 and 18.

correctly the common centre of gravity of the planet and the sun. Owing to the enormous mass of the sun this is, however, in all cases, comparatively near to the sun's centre. The second law is illustrated in fig. 15, where S represents the sun; AP, PQ, QR, &c., are portions of a planet's orbit described in equal periods of time; while ASP, RST, VSA′, &c., are the equal areas passed over by the radius vector in equal times. It is also easy to see from the second law that the velocity with which a planet moves in its orbit is greatest when least distant from the sun, and least when most distant. It follows also that, in the case of the earth, the apparent angular motion of the sun in his orbit—that is, his angular motion in longitude—will vary. The maximum angular motion of the sun is $1^\circ\ 1'\ 9{\cdot}9''$ on December 31, and the minimum angular motion is $57'\ 11{\cdot}5''$ on July 1.

The correct understanding of the third or harmonic law is so important that it is advisable to illustrate it by examples. Having found the distance of one planet, and knowing the periodic times from observation, the distance of any other planet may be found by simple proportion. The earth is the planet whose distance has been best ascertained, as explained in Chapter V., and for the sake of simplicity we may often take this distance as the 'astronomical unit.' Our proportion may be stated thus:—

(Earth's period)^2	:	(Planet's period)^2	::	(Earth's distance)^3	:	x^3, distance required
$(1)^2$	:	$(T')^2$	::	$(D)^3$	:	$(D')^3$

Multiplying the second and third terms together and dividing by the first, we get the required fourth term of the proportion.

1. What would be the distance from the sun of a planet having a period of eight years?

Calling the earth's distance 1—*i.e.* using it as the astronomical unit—and distance required D, we have—

$$(1)^2 \text{ year} : (8)^2 \text{ year} :: (1)^3 : (D')^3$$

that is, $1 : 64 :: 1 : (D')^3 \therefore (D')^3 = 64 \therefore D = 4.$

The distance is thus found to be four times the earth's distance.

2. Find the distance of the planet Venus from the sun, its period of revolution being given as 224·8 days.

Here we may write the proportion thus:—

$$\begin{array}{cccc} \text{Days} & \text{Days} & \text{Miles} & \\ (365{\cdot}25)^2 : & (224{\cdot}8)^2 :: & (93{,}000{,}000)^3 : & (D')^3 \end{array}$$

On working this out we find the distance of Venus to be about 67,000,000 miles.

3. What is the periodic time of the asteroid Hygeia, its mean distance from the sun being 3·14937 times the earth's distance?

By Kepler's law we have $D^3 : D'^3 :: T^2 : T'^2$—that is,

$$1^3 : 3{\cdot}14937^3 :: 365{\cdot}25^2 : T'^2$$

This shows T' to be 2,041 days nearly.

27. **Deductions from Kepler's Laws.**—As already remarked, Kepler's laws were derived from observation merely, and were given simply as facts. Their physical explanation was first fully set forth by Newton, who proved that they were necessary consequences of the laws of motion and universal gravitation. His demonstration led to the inferences set forth below.

'By Kepler's second law, the radius vector of each planet describes about the sun equal areas in equal times; hence it follows that each planet is acted upon by a force which urges it continually towards the centre of the sun. We say, therefore, that the planets *gravitate* toward the sun, and the force which urges each planet toward the sun is called its gravity toward the sun. By Kepler's first law, the planets describe ellipses, having the centre of the sun at one of their foci; hence it follows that the force of gravity of each planet toward the sun varies inversely as the square of its distance from the sun's centre. By Kepler's third law, the squares of the times of revolution of the different planets are as the cubes of the mean distances from the sun; hence it follows that the planets are solicited by a force of gravitation toward the sun, which varies from one planet to another as the square of their distance. It is, therefore, the same force, modified only by distance from the sun, which causes all the planets to gravitate toward him, and retains them in their orbits. This force is conceived to be an attraction of the matter of the sun for the matter of the planets, and is called solar attraction. This force extends infinitely in every direction, varying inversely as the square of the distance.'[1] Not only is the sun endowed with this attractive force, but the motions of the satellites about their primaries show that these bodies also exercise a similar attraction, and as a body is made up of its component particles, the gravi-

[1] Loomis.

tation of the earth or of any other planet towards the sun is the sum of the gravitation of these particles. Thus every particle attracts every other particle in the solar system, and indeed in the whole universe, with a force which varies inversely as the square of the distances of the particles, and all bodies mutually attract each other with forces varying directly as their quantities of matter or mass, and inversely as the square of their distances. This principle is the law of universal gravitation. (See Chapter XIII.)

The orbit which a planet would describe round the sun, if the planet and the sun were the only two bodies in the system, would be a perfect ellipse. But the existence of other planets and satellites introduces by their attractions small variations, spoken of as disturbances or *perturbations*. The treatment of perturbations is the most difficult part of the science of theoretical astronomy.

CHAPTER III.

LIGHT AND ASTRONOMICAL INSTRUMENTS.

28. **Nature of Light.**—Heat and light are forms of radiant energy, energy being the power to do work—that is, to produce motion against resistance. Both these forms of energy are now regarded as undulations propagated in the all-pervading medium called ether, and both are known to travel from their source at the enormous velocity of 186,000 miles per second. When a substance is heated its molecules are set into a state of vibration, and these vibrating molecules, setting the ether around in a state of vibration, communicate to it energy which travels in waves in all directions from the heated substance. At first these waves do not affect the eye, forming only rays of dark heat, but as the temperature rises the substance passes into a state of red heat, and finally, as the heat increases, the substance glows with a white heat. In the case of sound the waves are propagated in the air, the vibrations of the air particles taking place in the direction of the wave, but 'in light-waves the motion of any particle is confined to the plane perpendicular to the direction of propagation which passes through the particles, but may be of any small vibration in that plane.' An idea of such wave motion may be formed by taking a rope and suspending one end to a high ceiling. On shaking the rope at the lower end undulations will be set up, the particles of the

rope moving perpendicular to its length, but the onward motion of the form of the waves being in the direction of the length. Such in few words is a sketch of what is called the ***undulatory*** theory of light, now universally accepted. An older theory, called the ***emission*** or ***corpuscular*** theory, regarded light as consisting of very minute material particles given off by a luminous body and translated through space at the velocity before mentioned. But this theory failed to explain all the phenomena, and has consequently been abandoned.

That branch of physics which treats of light is termed Optics. We propose here to give only such parts as are required for the purposes of this book.

29. **Ray and Pencil of Light.**—A luminous point sends to the eye a divergent bundle or pencil of light-rays, the term *ray* being used to indicate the direction of the line in which light travels, and the pencil being regarded as formed of a vast number of such lines or rays. But, if the light proceed from a very distant body, as a star, the rays that reach the eye may be regarded as *parallel*.

30. **Media.**—A medium is any substance through which light can travel, as the ether, air, water, glass, &c. The medium is said to be homogeneous when it has the same chemical composition and density throughout. As long as light moves in a homogeneous medium it moves in a straight line, leaving shadows where it cannot fall. When it meets an object into which it cannot penetrate it is thrown back, or *reflected*, and when it passes from one medium to another one part of it is reflected at the surface of the second medium, while another part enters the medium, but is bent or *refracted* into a different direction. A portion of light is also *absorbed* as it passes into various media.

31. **Intensity of Light.**—The intensity of light diminishes as the distance increases; or the law of intensity may be more exactly expressed by saying that *the intensity of the illumination of an object varies inversely as the square of the distance of the object from the source of light.* Fig. 19 illustrates this law. From the candle C rays of light fall on the square board 1; at twice the distance the same number of rays is spread over four times the area; and at 3, placed at three times the distance, we have nine times the area illuminated by the same quantity of light.

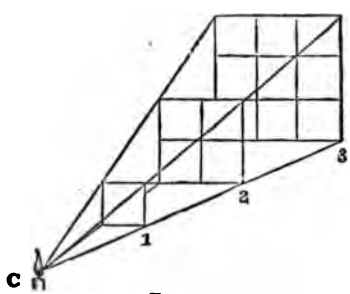

Fig. 19.

32. **Reflection of Light.**—When light falls upon rough and unpolished bodies it is scattered or reflected irregularly, but

when it falls upon smooth and opaque polished surfaces most of it is reflected regularly. Such surfaces are furnished by rendering quite smooth and bright, metals like silver, tin, steel, &c. In an ordinary looking-glass most of the light is reflected from the inner surface, which is coated with a thin layer of silver or mercury. As no surface can be rendered perfectly smooth, some of the rays falling on it are scattered or irregularly reflected, and these render the surface more or less visible. For the rays reflected regularly from a *plane* polished surface the following simple law holds:—*The angle of reflection is equal to the angle of incidence, while both the incident and the reflected rays are in the same plane, which is perpendicular to the reflecting surface.* The truth of this law may be rendered evident to the eye by allowing a sunbeam to enter through a small narrow opening in the shutter of a darkened room and receiving it on a mirror. The dust-particles of the room will make the path of the incident and reflected rays sufficiently visible. The light itself is really invisible, for if the floating dust-particles be removed from the air in an enclosed space, a beam of sunlight sent through this space cannot be seen.

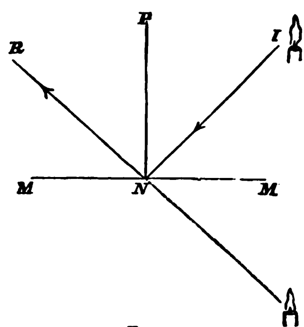

FIG. 20.

In fig. 20 P N R, the angle of reflection, is equal to the angle of incidence P N I, and they are on opposite sides of the perpendicular and in the same plane. An eye at R looking into the mirror would see the image of the candle at the same distance behind the mirror as the candle itself is in front.

33. **Reflection from Plane Surfaces.**—Plane mirrors show by reflection images of objects placed before them, the image appearing to be as far behind the mirror as the object is in front of it. As this image has no real existence, for the luminous rays do not come from behind the mirror, but only appear to do so, this appearance is called a *virtual* image. These facts are illustrated in fig. 21. The rays from the point A of the arrow proceed after reflection as if they had come from the point *a*, and the rays from the point B appear to come in a similar manner from *b*, these points

of the image being as far behind the mirror as the corresponding points are in front of it. The images of the intermediate points may be determined in a similar manner.

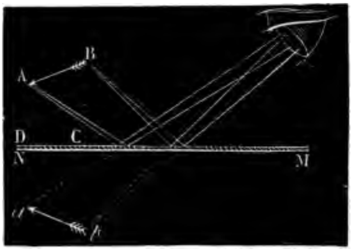

FIG. 21.

34. **Reflection from Curved Mirrors.**—The most important case of reflection from curved surfaces is that in which a concave spherical mirror receives light from a very distant source, so that the rays are parallel to the *principal axis*. The principal axis is the straight line A L (fig. 22), passing through the centre of the curve and the centre of the mirror; any other line passing through the centre C, but not through A, is a *secondary axis*. Such parallel rays intersect after reflection at a point F, midway between the centre of curvature C and the centre of the mirror A. The point where the reflected rays meet in front of the mirror is called the *focus*, and the focus of parallel rays is called the *principal focus*, while the distance A F is called the principal focal distance or *focal length*. It is a *real* focus, as the reflected rays do

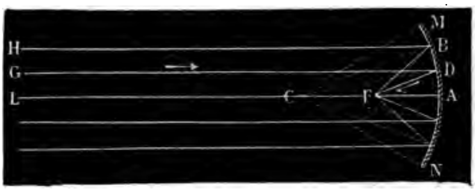

FIG. 22.

actually meet at the point, and the focal length is always equal to one half the radius of curvature. If the distant object be not a mere point but an object of a certain size, as the moon, we may conceive a secondary axis drawn from each point through the centre of the mirror. Each axis will then contain the focus of the parallel rays from some one point of the object, and the collection of foci will form an image of the object. Moreover it will be a real though inverted image, so that if a photographic plate were properly exposed at the focus of the mirror, a likeness of the object would be obtained.

35. When a ray of light moving in one medium arrives at another it undergoes various changes according to the nature

of the new medium. Part of it is reflected according to the manner already explained, and part of it is scattered or irregularly reflected, rendering the surface of the substance visible. This irregular reflection is greater, the more irregularly polished the surface of the body is which it meets. A part also enters the new medium, and is absorbed. In the case of opaque bodies the whole of the entering light is either reflected or absorbed, but in transparent bodies a large part of the entering light is transmitted through them when they are but thin. This transmitted light undergoes a change, of course, which we will now examine.

36. **Refraction of Light.**—When light passes obliquely from one transparent medium to another of different constitution, it deviates from its straight course as soon as it touches the new medium, being bent into a fresh direction. This deviation is known as the refraction of light. It occurs in all cases where light passes into a medium of different density, except when it falls perpendicularly to the surface separating the two media. On passing from a rarer into a denser medium a ray of light is always bent *towards* the perpendicular in the denser medium,

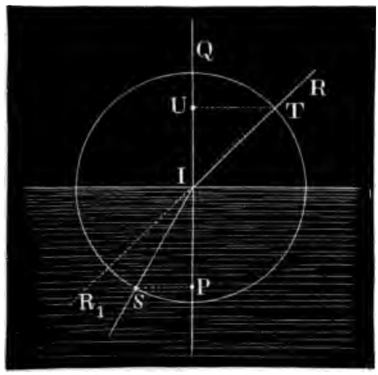

FIG 23.—Refraction.

and conversely, on passing from a denser into a rarer medium, it is bent *from* the perpendicular. Thus in fig. 23, if the ray R I passes from the air into water at I, it will be refracted in the same plane along the line I S, instead of continuing its course in the direction I R_1. The angle R I Q is called the angle of incidence, and the angle S I P is called the angle of refraction. The relative proportions of these two angles may be found by describing a circle from the point I, and letting fall perpendiculars from the points of intersection T and S upon the

line Q P. Now the fraction, perpendicular divided by hypotenuse, in a right-angled triangle is called in trigonometry the *sine* of an angle, and as the hypotenuse is the same—viz. a radius of the circle—for the angles of incidence and refraction, we see that the perpendiculars T U and S P may be taken as the measures of the sines of these angles. Now it is found that for the same two media the sine of the angle of incidence bears a fixed proportion to the sine of the angle of refraction, and this invariable ratio is called the *index of refraction* of the media. For air and water this ratio is expressed by the fraction $\frac{4}{3}$, or more accurately 1·34. For crown glass it is 1·53, for flint glass 1·64, and for diamond as much as 2·48, when light enters them from the air. We may now state the laws of refraction as follows: *The incident and refracted rays are in the same plane with the perpendicular at the point of incidence, and on opposite sides of the perpendicular, and the sine of the angle of incidence bears a ratio to the sine of the angle of refraction which is constant for the same two media.*

37. **Total Internal Reflection.**—In fig. 23 we took T I as the incident ray, and saw that the refracted ray S I, on passing through the denser medium, was bent towards the perpendicular common to the surface of the two media. If we suppose S I to be the incident ray, then on passing into the rarer medium the refracted ray I T will be bent away from the perpendicular, the angle T I U being greater than S I P. By allowing the angle S I P to increase, it is plain that on attaining a certain size the refracted ray will pass along the surface of the liquid. For any greater angle of incidence we should have no refracted ray passing into the upper and rarer medium, but the incident ray would be totally reflected back into the lower and denser medium on the opposite side of the perpendicular. This phenomenon is known as *total internal reflection.*

38. **Atmospheric Refraction.**—From what we have already said, it will be evident that the light from any celestial body on leaving the vacuum of space and entering the earth's atmosphere will undergo refraction. The following account of this phenomenon is in the words of the late Sir John F. W. Herschel, as contained in his 'Outlines of Astronomy':—

'Suppose a spectator placed at A' (fig. 24), 'any point of the earth's surface, K A *k*; and let L *l*, M *m*, N *n* represent the successive strata or layers of decreasing density into which we may conceive the atmosphere to be divided, and which are spherical surfaces concentric with K *k*, the earth's surface. Let S represent a star, or other heavenly body, beyond the utmost

limit of the atmosphere. Then, if the air were away, the spectator would see it in the direction of the straight line A S. But, in reality, when the ray of light S A reaches the atmosphere, suppose at *d*, it will, by the laws of optics, begin to bend *downwards*, and take a more inclined direction, as *d c*. This bending will at first be imperceptible, owing to the extreme tenuity of the uppermost strata; but as it advances downwards, the strata continually increasing in density, it will continually undergo greater and greater *refraction* in the same direction, and thus, instead of pursuing the straight line S *d* A, it will describe a curve S *d c b a*, continually more and more concave downwards, and will reach the earth, not at A, but at a certain point *a*, nearer to S. *This* ray, consequently, will not reach the spectator's eye. The ray by which he will see the star is, therefore, not S *d* A, but another ray, which, had there been no atmosphere, would have

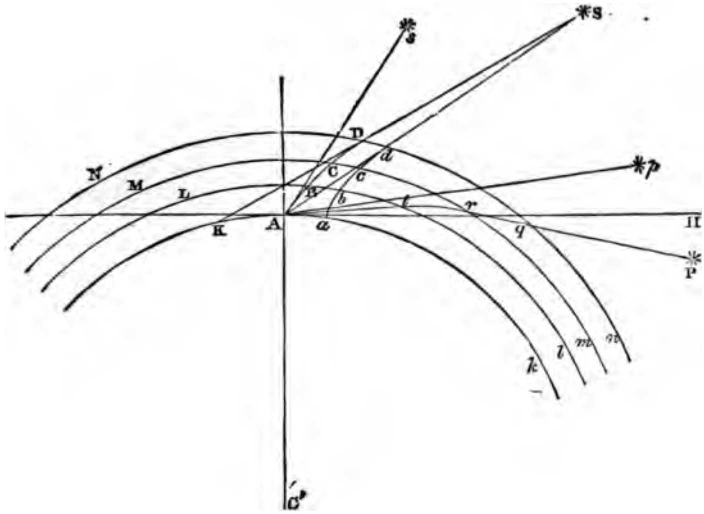

FIG. 24.

struck the earth at K, a point *behind* the spectator; but which, being bent by the air into the curve S D C B A, actually strikes on A. Now, it is a law of optics, that an object is seen in the direction which the visual ray has at the instant of *arriving at the eye*, without regard to what may have been otherwise its course between the object and the eye. Hence the star S will be seen, not in the direction A S, but in that of A *s*, a *tangent* to the curve S D C B A, at A. But because the curve described by the refracted ray is concave downwards, the tangent A *s* will lie *above* A S, the unrefracted ray; consequently the object S will appear more elevated above the horizon A H, when seen through the refracting atmosphere, than it would appear were there no such atmosphere. Since, however, the disposition of the strata is the same in all directions around A, the visual ray will not be *made to deviate laterally*, but will remain constantly in the

same vertical plane, S A C′, passing through the eye, the object, and the earth's centre.

'The effect of the air's refraction, then, is to *raise* all the heavenly bodies higher above the horizon in appearance than they are in reality. Any such body, situated actually *in* the true horizon, will appear *above* it, or will have some certain apparent *altitude* (as it is called). Nay, even some of those actually below the horizon, and which would therefore be invisible but for the effect of refraction, are by that effect raised above it and brought into sight. Thus, the sun, when situated at P, below the true horizon A H of the spectator, becomes visible to him as if it stood at *p*, by the refracted ray P *q r t* A, to which A *p* is a tangent.

'To determine with accuracy the exact amount of atmospheric refraction is a problem of great difficulty, for the amount varies not only with the zenith distance of the celestial object, but it is also affected by the varying temperature and moisture of the air. The following general statement may be usefully borne in mind :—

'(1) In the *zenith* there is no refraction. A celestial object situated vertically overhead is seen in its true direction, as if there were no atmosphere, at least if the air be tranquil.

'(2) In descending from the *zenith* to the horizon the refraction continually increases. Objects near the horizon appear more elevated by it above their true directions than those at a high altitude.

'(3) The *rate* of its increase is nearly in proportion to the tangent of the apparent angular distance of the object from the zenith. But this rule, which is not far from the truth at moderate *zenith distances*, ceases to give correct results in the vicinity of the horizon, where the law becomes much more complicated in its expression.

'(4) The average amount of refraction for an object half-way between the zenith and horizon, or at an apparent altitude of 45°, is about 1′ (more exactly 57″), a quantity hardly sensible to the naked eye ; but at the visible horizon it amounts to no less a quantity than 33′, which is rather more than the greatest apparent diameter of either the sun or the moon. Hence it follows that when we see the lower edge of the sun or moon just *apparently* resting on the horizon, its whole disc is in reality below it, and would be entirely out of sight and concealed by the convexity of the earth but for the bending round it which the rays of light have undergone in their passage through the air, as alluded to already.

'(5) That when the barometer is higher than its average or mean state the amount of refraction is greater than its mean amount; when lower, less; and,

'(6) That for one and the same reading of the barometer the refraction is greater the colder the air.'

From what has been said in the above quotation it follows that one effect of refraction is to increase the time of daylight, as we are thus enabled to see the sun before it has actually risen, and also after it has set. But even after the sun has disappeared below the horizon light remains in the atmosphere. This illumination of the atmosphere before sunrise and after sunset is known as *twilight*. It is caused by the reflection of

ght to the observer from the vapours and particles of floating ıatter in the higher regions of the atmosphere. It is generally ɔnsidered that twilight lasts until the sun is about 18° below ıe horizon. The time required to reach this point is longer in igh latitudes than in low latitudes, as the sun in the former ıse has to traverse a longer arc to reach 18° of vertical depres- on than in the former case, where the sun descends perpen- icularly to the horizon. In latitudes exceeding 49° there is in ımmer no real night, as the sun at midnight does not reach 18° elow the horizon. Near the equator the twilight is said to last ot more than twenty minutes, while in the south of England varies from about two and a quarter hours at midsummer to ne and a half hours at mid-winter. The ordinary diffused light f day may be referred to the same cause as twilight—the regular reflection or scattering of light from clouds and other articles floating in the air.

39. **Lenses.**—When a ray of light falls on a plate of glass ith parallel surfaces it is first bent towards the perpendicular, ıd on passing into the air again it will again deviate by an ɿual amount from the perpendicular at the inner surface, so ıat the emergent ray will always remain parallel to the incident ıy. But if the surfaces of the glass be not parallel but curved,

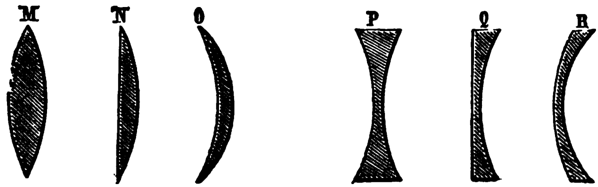

FIG. 25.

ıe rays of light which pass through them will either converge r diverge. Transparent substances possessing curved surfaces ːe called *lenses*. They are usually made either of crown glass r of flint glass. The latter kind contains lead, and is more ːfractive than crown glass. Six different forms of simple lenses ːe shown in fig. 25.

M is a double convex lens; N, a plano-convex; O, a concavo- ɔnvex; P, a *double concave*; Q, a plano-concave; and R, a

concavo-convex. The first three are converging lenses, and the other three diverging lenses. When a converging lens receives a pencil of rays from a very distant source, these rays, after being twice refracted, are brought to a point, F (fig. 26) (so long as the arc D E forms but a small fraction of the circle of which it is a part). The point to which parallel rays are thus

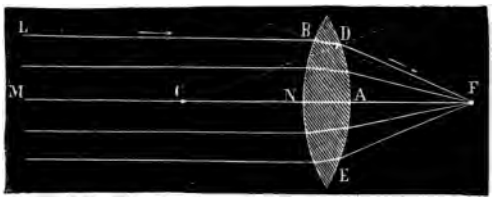

FIG. 26.

made to converge is called the *principal focus* of the lens, and the distance F A is called the principal focal distance. The principal focus of a convex lens may be found by exposing it to the sun's rays, so that they fall upon it parallel to the axis. The rays, after passing through the lens, may be received on a ground-glass screen, the point to which they converge being found by

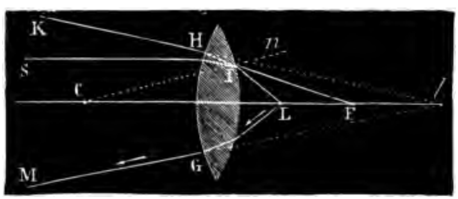

FIG. 27.

trial. The distance of the screen from the lens will then give the focal distance of the lens. If the luminous point be not so far as to render the rays sensibly parallel, then the divergent pencil of rays is brought to a point which is more distant than the principal focus F. When the luminous point coincides with the principal focus F, the emergent rays on the other side are parallel to the axis, so that the focus may be said to be at

an infinite distance; while in the case of the luminous object being placed between the lens and the principal focus, as at L, fig. 27, the rays from the point, though rendered less divergent, still form the diverging pencil H K, G M. These rays, therefore, do not give rise to any real focus, but their prolongations intersect at the point *l*, which is the virtual focus of the point L.

40. A concave or diverging lens has an opposite effect on a pencil of light to that of a convex or converging lens, making parallel rays divergent, and convergent rays less convergent, or even parallel or divergent. Convex lenses are sometimes called *negative* lenses, and concave lenses *positive* lenses, because, when the origin of light is very distant, a convex lens brings the rays to a focus on the opposite side of the lens, and a concave lens to the same side of the lens as the source of light.

41. **Formation of Images by Lenses.**—When an object is placed before a lens, an image of this object formed of the collection of the foci of its several points may be produced, and this image can then be seen by an eye placed in a suitable position. When the object is placed at a distance greater than the focal length of the lens, a real inverted image is found on the other side of the lens. Thus, in fig. 28, from the point A of

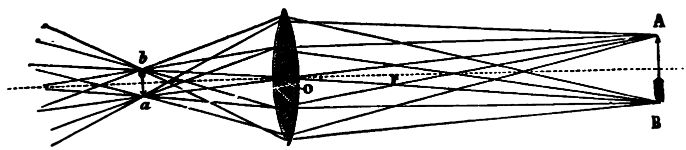

FIG. 28.

the image a pencil of rays diverge, and after undergoing refraction in the lens this pencil is brought to a focus at *a*. Similarly the pencil of rays from the point B will be brought to a focus at *b*. Points intermediate between A and B will be made to converge to corresponding points between *a* and *b*. The image thus formed may be received on a suitable screen, or it may be viewed by an eye placed in the path of rays proceeding from it. When the object is at a very great distance the image that is formed will be found at the principal focus of the lens, and this image like the preceding is smaller than the object. The object and the image are, in fact, in the same proportion as their distances from the lens.

When the object is placed between the lens and the principal focus, this image that is formed is erect, virtual, and behind the lens. Moreover, the image is larger than the object, the magnifying power of the lens in this case being greater in proportion as the lens is more convex and the object nearer the principal focus. Fig. 29 illustrates how a convex lens may be made to *magnify* an object placed *within* the principal focal distance. The rays from the object A B after passing through the lens will appear to proceed from the image *a b*, the points *a* and *b* being situated on the lines joining the centre of the lens to the points A and B. The image is viewed by an *eye placed* close to the opposite side of the lens, the

lens being so arranged that the image shall be situated at the distance of distinct vision. This may be taken at about 10 inches on the average. Looking through the lens at the object A B (the eye could not see it without the aid of the lens, as the rays from it would be too divergent for distinct vision) we can see the image plainly, and this image is larger than the object would appear if it were placed at a distance of 10 inches and viewed without the lens. We thus see why convex lenses are sometimes spoken of as magnifying glasses. The images of objects produced both by spherical lenses and mirrors are true only for the rays that lie near the axes. Other rays are not brought to a focus at a single point, and these produce a want

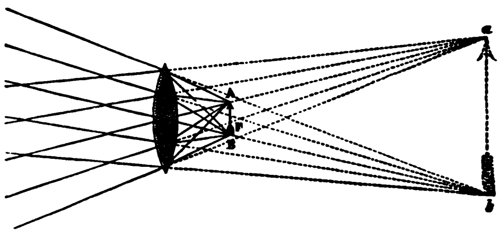

FIG. 29.

of sharpness and clearness in the image which is called *spherical aberration*. For mirrors and lenses whose aperture—the angle formed by joining the edges to the principal focus—does not exceed 10° or 12°, spherical aberration hardly exists, but with a greater aperture it causes much inconvenience. Another defect of lenses is spoken of as *chromatic aberration*, the images they produce having at certain distances from the eye coloured edges (Gr. *chroma*, colour). This is due to the fact (as will be explained more fully in the next chapter) that white light consists of a number of different coloured rays all intermingled. These rays are of unequal refrangibility, and are therefore somewhat dispersed or brought to slightly different foci when white light passes through a converging lens. The image formed is, therefore, a little indistinct, and has coloured fringes. This effect may be obviated by the use of a compound lens made of two lenses of unequal dispersive materials, one a diverging concavo-convex of flint glass, the other a double convex of crown glass. These two kinds of glass, having different refractive and dispersive effects on white light, and the refractive power of a body not varying in the same ratio as the dispersive power, can be so apportioned that the differently coloured rays in white light can be all made to come to one focus. Such a compound lens is called an *achromatic lens* (Gr. *a*, not; *chroma*, colour). (*See* fig. 30.)

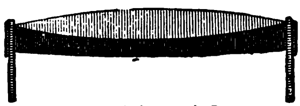

FIG. 30.—Achromatic Lens.

42. **The Astronomical Telescope.**—A telescope consists essentially of a tube which contains two convex lenses, one of which, L, called the object-glass, forms, as just explained, an

inverted image, *b a*, of a distant object, A B; while the other lens, L′, called the eye-piece, magnifies the image that is formed. The tube serves to keep the glasses in their proper relative positions, and to shut off stray light from the observer's eye. This magnified image is represented by *b′a′*. In astronomical work, where the objects are at a great distance, and the rays from any point therefore practically parallel, the image formed by the object-glass is at a distance from this glass equal to its focal length. The eye-glass, L′, is placed at such a distance from the image *b a* that the eye of the observer sees the magnified image at the distance of distinct vision (about 10 inches). As this varies somewhat in different persons, the tube containing the eye-piece can be moved, so that by

FIG. 31.

focussing the magnified image, as it is called, it can be made clearly visible.

43. **Magnifying Power of a Telescope.**—The distant object subtends at O, the centre of the object-glass, an angle equal to A O B, and this is the same angle which the object subtends to the unaided eye, for the comparatively small length of the telescope tube makes no difference. The object seen through the telescope appears as the image *b′a′*, and this subtends the the much larger angle *b′o′a′*. Now the apparent magnitude of any object is the angle formed at the centre of the pupil of the eye by two rays drawn from the extremities of the object, and it is easily seen that the apparent magnitude of one of the dimensions (as the diameter) varies inversely as the distance of the object from the observer's eye. The telescope, therefore, virtually carries the eye so near to the object that it subtends the larger angle *b′o′a′*, and the object is magnified in the ratio of the angle *b′o′a′* to A O B, represented by the fraction

$\frac{b'o'a'}{AOB}$. Now these angles can be shown to have very nearly the same ratio to each other that the distance of the small image *b a* from the object-glass has to the distance of the same image from the eye-glass. As these distances are the same as the focal lengths of the two lenses respectively, we arrive at the following : *The magnifying power of a telescope is equal to the focal length of the object-glass divided by the focal length of the eye-glass.* By changing the eye-lens for one of smaller focal length we can evidently increase the magnification of the image. Many telescopes have consequently several eye-pieces. But this magnification has limits if we wish to retain an image sufficiently bright.

44. **Brightness of the Image.**—The object-glass when pointed to a distant object transmits to the eye of an observer with the assistance of the eye-piece all the rays which fall upon it, leaving out of account what is lost by absorption and reflection at the different surfaces. Hence the quantity of light received is as many times greater than would be got without the telescope as the area of the object-lens is greater than the area of the pupil of the eye. Taking the area of the pupil at one-fifth of an inch, we see that a three-inch telescope increases the quantity of light about [illegible]5 times, while the great Lick telescope, which has an object-glass of 36 inches aperture, increases it 32,400 times, the amount being in direct proportion to the square of the diameter of the lens. This shows how a telescope can render visible objects unseen by the unaided eye. Multitudes of the stars are never seen as we gaze around us, as the pupil is not able to gather sufficient light to produce an impression upon the retina, but by the aid of the object-glass of the telescope an increased quantity of light is poured into the eye, and the fainter objects are revealed. In the case of *extended* objects, however, like the moon or a planet with a disc, there is no increase of brightness, as such an object can by no arrangement be made to appear brighter than it does to the unaided eye. We now see why there is a limit to the magnifying power of the eye-glasses that may be advantageously used with the same object-glass. Each increase of magnification of the image formed by the object-glass renders the enlarged image formed by the eye-piece less brilliant, as the same quantity of light is spread over a greater area. Too great magnification will therefore render this image indistinct.

45. **Perfection of the Image.**—If the object-glass gathered to a single point in the image formed at its focus all the rays which proceeded from the corresponding point of the object, we should have a perfect image of the object. But no single lens can do this, and hence two defects arise, spherical aberration and chromatic aberration. The former defect is corrected

as far as possible by choosing lenses whose radii of curvature are of the best form, and the chromatic aberration is almost destroyed by using the achromatic object-glass described in par. 41. A section of an *achromatic astronomical refracting telescope* is shown in fig. 32. A is the achromatic object-glass placed at the further extremity of the tube at right angles to its axis; F is the tube containing the eye-piece, and it slides in and out of the tube D C by the aid of the rack and pinion *r*. The eye-piece is composed of two plano-convex lenses with the flat sides next the eye. This kind of eye-piece, called the negative or

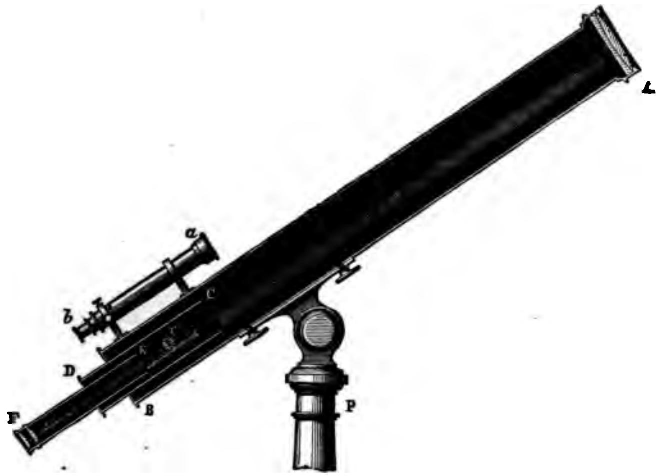

FIG. 32.

Huyghenian eye-piece, is often used instead of a single convex lens, as thereby the chromatic aberration of the *eye-piece* is corrected, and distortion at the margin of the field of view is prevented. The one nearer the image is called the field-lens, and the one nearer the eye the eye-lens. In an astronomical telescope the image is always seen *inverted* and the right side left, but the observer soon becomes accustomed to this. For terrestial purposes an erecting eye-piece may be introduced in order to show objects in their proper positions.

46. **Reflecting Telescopes.**—In some telescopes the image

of the distant object is formed by a mirror of speculum metal or one of silver on glass, instead of being formed by a lens. Various forms of such reflecting telescopes are in use. The Newtonian reflector is probably the one most used. A diagram explaining its construction is annexed (fig. 33). The end, *h i*, of the tube is quite open, and directed towards the distant object. The opposite end is closed by a concave mirror, *c d*. This mirror would produce a small inverted image of the object a_1b_1, but before convergence the rays going to form this image are intercepted by the small inclined mirror *s s*, which reflects them at right angles to the axis of the telescope to form

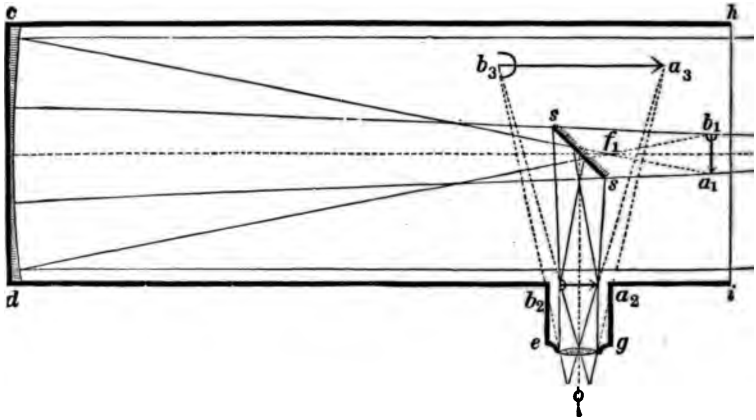

FIG. 33.—Newtonian Reflecting Telescope.

the image a_2b_2. In this place a smaller tube is attached, which carries the eye-piece *e g*. This eye-piece forms for an eye placed at *o* a virtual magnified image, a_3b_3. At one time the large mirror was made of an alloy of tin and copper called speculum metal, but it is now made of glass coated with a thin layer of silver on the front surface. The largest telescope in the world is a Newtonian reflector. It was made for the late Lord Rosse, and has a mirror 6 feet in diameter, and of 60 feet focal length. The largest refractor is at the Lick Observatory, on Mount Hamilton, in California. The object-glass has an aperture of 36 inches and a focal length of 56 feet.

47. **The Transit Instrument.**—Astronomers set up or mount their telescopes in various ways to suit different purposes. A transit instrument is a telescope A B, mounted on trunnions like a cannon, and made to sweep over the meridian of the place where it is fixed. A rigid axis at right angles to its length rests on two equal cylindrical pivots X and Y at the top of two fixed posts or pillars of solid masonry, L and M (fig. 34). The axis is placed perfectly horizontal and accurately east and west, so that the telescope itself swings vertically north and south. It is thus able to move only in the plane of the astronomical meridian of the place where it is fixed, and it can be set to any altitude in that plane. The instrument is used in connection with a sidereal clock or chronometer to observe the exact time at which a star's transit across the meridian occurs. Inside the telescope, at the focus of the object-glass, and therefore near the eye-piece A, is a frame or reticle (fig. 35) across which are stretched five or seven fine vertical lines or wires, usually threads of spider's webs. These lines are at equal distances apart, and crossed by one or more lines at right angles.[1] The imaginary line joining the point of crossing O (fig. 35) with the centre of the object-glass is called the *line of collimation*, and when these wires are so adjusted that this line is at right angles to the axis resting on the pivots, the telescope is said to be correctly *collimated*. When the instrument is thoroughly rigid and the pivots perfectly true, and when it is accurately adjusted so that the axis is exactly level and pointing true to the east and west, the collimation being also perfect, then the central vertical wire will always move on the meridian as the telescope is turned. The moment when a star crosses this wire will therefore be the true moment of the star's meridian transit. When the star comes into the field of view,

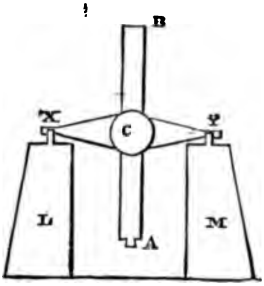

FIG 34.—Transit Instrument.

[1] In order to see the wires at night the axis X Y is perforated, so that the light of a lamp placed at X passes through the opening to a small mirror in the *centre of the tube, from which it* is reflected down to the reticle.

the time of its passing each vertical wire is noted on the sidereal clock, and the average of these gives the moment of passing the central wire or meridian. This time fixes *the right ascension* of the object, for the right ascension of an object, when expressed in time, is simply the sidereal time at which it crosses the meridian—*i.e.* the number of hours, minutes, and seconds since the last preceding transit of the first point of Aries (par. 11). A sidereal clock, it will be remembered, indicates 0 h. 0 m. 0 s. when the vernal equinox crosses the meridian, so that a star which passes the meridian at 16 h. 28 m. 12 s. will have its R.A. 16 h. 28 m. 12 s.—*i.e.* 247° 3′ when expressed in arc.

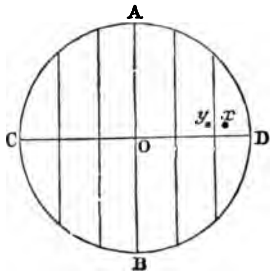

FIG. 35.

If the R.A. be known exactly (and this is given for certain important stars in the 'Nautical Almanac'), then the observation of the meridian passage of a star will give the opportunity of testing the accuracy of the sidereal clock. If a clock shows 3 h. 17 m. 49 s. at a star's transit when the true R.A. is 3 h. 17 m. 46 s., then the *error of the clock* is 3 s., and this amount of correction must be applied to any R.A. observed.

48. **The Transit or Meridian Circle.**—This is a transit instrument with a graduated circle of two or three feet diameter attached to the axis and revolving with the telescope. In some cases there are two circles, one at the end of each axis, and divided from 0° to 360°. Each degree of the graduated circle is in some instruments subdivided into thirty parts, so that the divisions are only 2′ apart. By means of microscopes as X Y (fig. 36) attached to the solid pier, the circle can be read to tenths of a second. By the aid of this instrument we can find the *declination* of a star at the same time as we find its right ascension. When the telescope points to a star at the moment that it is on the meridian so that it is crossing the central vertical wire at O, fig. 35, the position of the graduated circle is carefully noted. Suppose the graduation is so arranged that *the reading of* the circle is 0° when the telescope points to the

zenith. Then when we observe a star as it transits the meridian the reading of the circle will give us the zenith distance. As, however, it is scarcely possible to know when a telescope points exactly to the zenith, the zero point of the graduation is often placed at the *nadir*. This point can be precisely determined by pointing the telescope downwards to a basin of mercury, and moving it until the reflected image of the cross wires at the focus of the telescope coincides exactly with the cross itself. The horizon is just 90° from the nadir, and the zenith just 90° from the horizon. The difference between the reading of the circle at the time of transit and at observing the nadir point diminished by 90° will give the meridian altitude of the star. The complement of this is the zenith distance, from which, knowing the elevation of the pole above the horizon—that is, the latitude of the place—we can readily obtain the polar distance or its complement, the declination. An older instrument, called the *mural circle*, was formerly used to determine the declination of stars, but it has now been generally superseded by the transit circle. In principle it is the same as the transit circle, and consists of a vertical graduated circle carrying a telescope mounted so as to turn on the face of a wall.

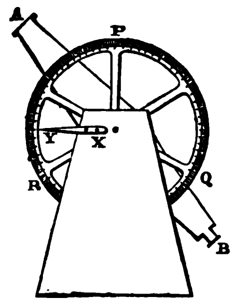

Fig. 36.—Meridian Circle.[1]

Observations for determining declination must be corrected for *refraction*, and in the case of all heavenly bodies but the fixed stars for *parallax* also. Parallax is explained later.

49. **The Equatorial Telescope.**—If we take a pair of open compasses and point one leg to the Pole star, then by turning this leg round, still keeping it in the same direction, the other leg may be made to follow a star in its diurnal circle. This will help in giving some idea of the motion of one part of an equatorial. The equatorial telescope is an instrument mounted on two axes at right angles to one another. One of these axes is pointed to the pole of the heavens, and is therefore parallel

[1] See larger figure in Appendix.

to the earth's axis, while the other is attached at right angles to one end of this, and is called the declination axis. The end of the polar axis bears a graduated circle parallel to the equator, called the hour circle, because its reading gives the hour angle of the object to which the telescope is pointed, while the declination axis bears at its upper end the telescope, and near its lower end the declination circle. Having turned the telescope on its declination axis till the reading of the declination circle corresponds to the declination of the object, and having also turned the polar axis until the hour circle of the instrument corresponds with the distance of the object from the meridian, the star may be followed in its circle of declination by merely turning the instrument on its polar axis. With all large equatorials the polar axis is turned by clockwork movement at an angular velocity exactly equal to the angular velocity with which the earth rotates on its axis. The astronomer is thus able to fix his telescope on a star and keep it in the field for hours by following it in its daily motion. In the figure A B is the polar axis, C D the declination axis, E a small telescope called the finder, F the hour circle or right ascension circle, G the declination circle, O the clock with weight W for turning the telescope by the wheel R, which on its polar axis is connected with an upright shaft S, K the eye-piece and micrometer, L a lamp to illuminate the cross-wires at night.

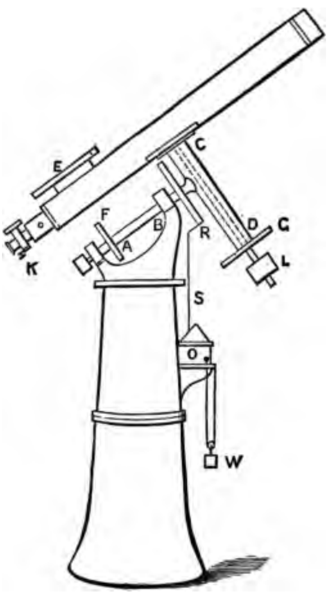

FIG. 37.—Equatorial Telescope.

In the figure the telescope is represented as pointing to the Pole, but it may be turned on its declination axis to point in any other direction, so as to bring a celestial object at any polar

distance—or at any declination—into the field of view. On clamping this axis when it points to an object, and then turning the telescope round the polar axis from east to west, the instrument will describe a circle parallel to the equator, thus enabling the observer to follow the daily rotation of any heavenly body.

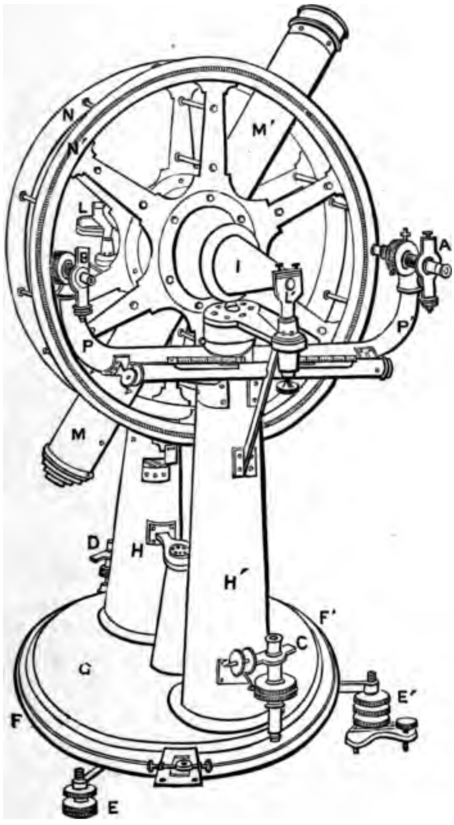

FIG. 38.—The Altazimuth.

50. **The Altazimuth.**—The altazimuth is an instrument used to measure the altitude and azimuth of heavenly bodies. A telescope, M M', is *mounted* between two vertical pillars,

H H′, these pillars resting on the strong circular plate G. This plate and the whole of the upper works turn on a vertical axis concentric with the azimuth circle F F′, and thus the telescope may be directed to any point of the horizon. The circular plate G carries a pointer to show the degree and the nearest twelfth to be read off the azimuth circle F F′, the remaining minutes and seconds being obtained by means of the two reading microscopes C and D. E and E′ are two of the screws of the tripod on which the instrument rests, and they serve to adjust the instrument to perfect horizontality. The telescope is fixed between the circles N N′, and can be moved on its axis I to any altitude. A and B are the two microscopes for reading the indications on the graduated ring of silver inlaid on the altitude circle N. They are carried by the two strong arms P P′ attached near to the top of the pillar H′.

Thus the altazimuth is essentially a telescope capable of revolving in two planes at right angles to one another, the angle of revolution in each case being measured by a graduated circle. Let the index of the horizontal circle point to zero when the telescope points due south, and the index of the vertical circle to zero when the telescope points to the zenith. If the instrument be now turned so as to point to a star in any part of the sky, the reading of the horizontal circle F F′ will give the azimuth, and the reading of the vertical circle N′ will give the zenith distance, and 90° − zenith distance = the altitude (par. 10).

A *theodolite* is simply an altazimuth adapted to the use of a surveyor, who requires a portable instrument for measuring horizontal and vertical angles on the earth's surface. It is made perfectly horizontal by means of a spirit-level, and is usually mounted on a large tripod when in use.

51. The *zenith sector* is also a modification of the altazimuth. It is especially used to determine the zenith distances of stars near the zenith, its essential parts being a plumbline and a telescope, moving at the eye end over a carefully graduated arc. The angle between the plumbline and the axis of the telescope when pointing to a star on the meridian of the place of observation is the zenith distance of the star (par. 10).

52. **The Sextant.**—The sextant is an instrument used for measuring the angular distance of two remote points or the altitude of celestial objects. It is especially adapted for use at sea, where fixed instruments are of no avail. It consists of a graduated circular arc, B C, connected by two metallic arms, A B, A C, with centre A. A D is a third movable arm, known as the radius bar, which revolves round a pin passing through the centre A. A plane mirror, called the index-glass, is fixed perpendicularly to the radius bar, and moves with it.

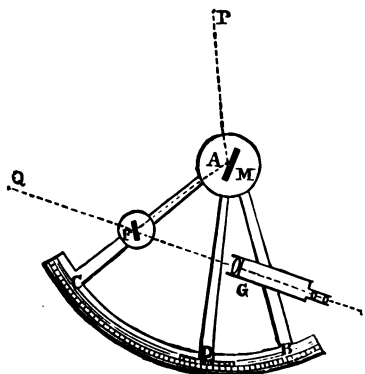

FIG. 39.

The arc C B of the sextant is graduated, and the movable bar A D bears at the lower end a vernier scale for subdividing the graduations of the arc. This vernier is read by a lens not shown in the figure. At F, on the arm A C, is the horizon glass or fixed reflector, the lower half of which is a plane mirror and the upper half unsilvered glass. G is a small telescope on the arm A B directed towards the mirror F, so that its axis, which must be parallel to the plane of the arc, meets the mirror at the boundary of the silvered and unsilvered portions. The horizon glass is fixed on the arm A C in such a position that, when M is parallel to it, the reading on the arc shall be zero. For observations on the sun both mirrors are supplied with coloured glasses of different degrees of shade, framed and placed in such positions that they can be turned down before the mirrors so as to diminish the intensity of the light.

In order to observe the angle between two distant objects, P and Q, the observer at the telescope holds the sextant so that its plane may pass through both objects, and looks directly at the lower or left-hand object, Q, through the fixed reflector F; he then moves the radius bar, and with it the mirror M until he sees the image of the other object P, at

the same time. This image reaches the eye after successive reflections at M and F— that is, by the path P A F G. By adjusting the position of the arm A D, the images of P and Q may be made to coincide exactly in the centre of the field of view.

The reading on the arc B D now gives the angle between the two mirrors, which is *half* the angular distance between the two objects P and Q. That the angle between P A and Q F is *double* the angle between the mirrors depends on the optical law that the direction of a ray of light reflected from the surface of a plane mirror is changed by twice the angle through which the mirror is turned. In many instruments the graduations of the arc are so numbered that they read as double of their real value, and then the reading of the vernier gives directly the real value of the angle which the two distant objects subtend at the observer's eye.

53. **The Vernier.**—The length of an object is often measured by reading off the number of divisions on a fixed scale applied

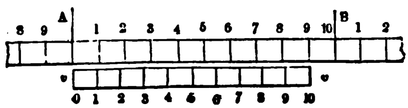

FIG. 40.

to the object, while the angles are measured by reading off the number of degrees and subdivisions of a degree in a certain arc. Where lengths or angles are required to be measured with great accuracy a *vernier* must be used. This instrument was invented by a French mathematician, Pierre Vernier, in 1631, and consists of a small graduated scale or arc made to slide along a larger fixed scale or arc, so as to enable us to read the position of the index when it lies *between* the graduations of a fixed scale. The principle of the instrument is illustrated by the preceding figure. A B is a portion of the graduated scale of an instrument showing what represents an inch subdivided into tenths ; *v v* is the vernier or small scale made to slide along the fixed scale. The vernier is divided into ten equal parts, but its ten divisions equal nine of the fixed scale.

Hence each part of the vernier is less than a part of the *scale by* $\frac{1}{10}$ *of the* latter—*i.e.* by $\frac{1}{10}$ of $\frac{1}{10}$ or $\frac{1}{100}$ of an inch.

Suppose the zero of the vernier to coincide with the division A on the scale, then the first division of the vernier will be found to be $\frac{1}{100}$ of an inch behind the first after A on the scale, the next line on the vernier will fall behind the next on the scale by $\frac{2}{100}$, and so on. If the vernier be slid along the scale slightly so that 1 on it coincides with a division on the scale, then the o of the vernier would be $\frac{1}{100}$ of an inch from the point A on the scale; if the 3 on the vernier be made to coincide with a division on the scale, the o of the vernier is $\frac{3}{100}$ above the division at A, and so on.

It is plain, therefore, that with the scale and the vernier we can read to hundredths of an inch.

'Suppose, for example, the position of the vernier with respect to the scale to be as represented in the annexed figure, where the zero of the vernier is brought to coincide with a certain point p on the scale. The point p is read on the scale 29 inches, $\frac{2}{10}$, and a fraction which is to be measured by the vernier. Here the division 6 on the vernier coincides with that which is marked 8 on the scale, therefore the distance of

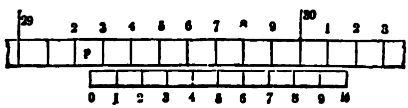

FIG. 41.

the zero of the vernier from the last division 2 behind it on the scale is $\frac{6}{100}$ of an inch; for as 6 on the vernier coincides with 8 on the scale, the distance of 5 from 7 is $\frac{1}{100}$; of 4 from 6, $\frac{2}{100}$; of 3 from 5, $\frac{3}{100}$; of 2 from 4, $\frac{4}{100}$; of 1 from 3, $\frac{5}{100}$; and of o from 2, $\frac{6}{100}$. In like manner, if the vernier were pushed along till the division 8 coincided with 30 inches on the scale, then the reading of the zero point would be 29 inches $\frac{2}{10}$ and $\frac{8}{100}$.' A vernier scale has usually one graduation more than the corresponding portion of the other scale. Calling the length of the fixed scale that contains the same number of divisions as the vernier scale a, and the number of these divisions n, the vernier will be equal in length to $n-1$ of these divisions, but will be divided into n equal parts. Since the distance a contains n equal parts, each division on the scale $=\frac{a}{n}$. As the length of the vernier $=a-\frac{a}{n}$ and as it is divided into n equal parts also, each division on the vernier $=a-\frac{a}{n}$ divided by n—*i.e.* $\frac{1}{n}\left(a-\frac{a}{n}\right)=\frac{a}{n}-\frac{a}{n^2}$. This shows that the difference between a division on the scale and one on the vernier is $\frac{a}{n^2}$. In barometers the inches are divided into twentieths. The vernier is made equal to twenty-four of these, and divided into twenty-five

equal parts. In this case the length a, or twenty-five divisions of the fixed scale $= 1 \cdot 25$ inches. As $n = 25, \frac{a}{n^2} = \frac{1 \cdot 25}{625} = \cdot 002$ inch. The instrument can, therefore, be read to $\frac{1}{500}$ of an inch.

In astronomical instruments the graduated scale is circular, so that the vernier is circular also, and must move concentric with the limb of the astronomical circle. In fig. 42 the limb of the sextant DL is divided into intervals of 20′. The number of divisions is twenty on the vernier TV, which are equal to nineteen on the scale. Hence we have $a = 400$, and $n = 20$; therefore the difference $\frac{a}{n^2} = \frac{400}{400} = 1$. We can thus read to 1′. In figure 42 the index or zero point shows an angle of 3° 30′ on the arc. If the division 11 on the vernier were coincident with a division on the scale instead of 10 on the vernier as in the figure, the reading would be 3° 31′.

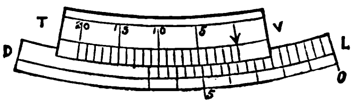

FIG. 42.

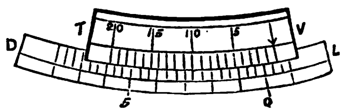

FIG. 43.

Figure 43 shows a reading of 30′ off the arc.

Mechanical subdivision of the limb of an instrument may be carried to 10′ or even less with satisfaction, and by increasing the length and the number of divisions on the vernier, still smaller quantities may be read off. If the vernier embrace fifty-nine of such intervals of 10′ and be divided into sixty equal parts, it will be evident from what has been said that with such an instrument the reading can be obtained to 10″ (ten seconds of arc).

A microscope or lens fixed over the vernier is needed to read these small divisions and to see where the two graduations coincide. In case no two graduations coincide an estimate may be made by assuming coincidence where it appears closest.

54. **Micrometer.**—In exact astronomical work the vernier is replaced by a micrometer, by means of which very minute displacements can be more safely ascertained.

Fig. 44 illustrates the parallel-wire micrometer, in which two parallel wires or threads, C and D, are so mounted on sliding frames that they can, by suitable screws, be made to coincide with each other or to separate by a small distance. A third wire, E, crosses the parallel wires at right angles. In using the micrometer with a telescope the

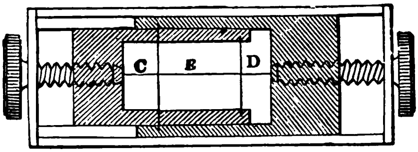

FIG. 44.

frame carrying the wires is placed at the common focus of the object-glass and the eye-piece. When determining the angular distance between two stars near together, the observer moves the vertical wires so that each passes through a star, the frame being so turned that these wires are at right angles to the line joining the stars. The wires may now be closed up by turning one of the screws till they exactly cover each other. The number of turns and fractions of a turn required to do this gives the interval between the threads in lineal measure. The micrometer screw is cut very fine and even, so that each complete turn of the screw-head represents, say, $\frac{1}{25}$ of an inch. The screw-head may be divided into 100 parts, so that a motion of one of these parts carried the screw through a distance of $\frac{1}{2500}$ of an inch. By means of a vernier attached to the screw-head, we may even read to the thousandth part of a turn of the screw. Having ascertained from the number of turns and fractions of a turn the lineal distance between the parallel wires when passing through two close stars or when on the opposite margins of a planet's disc, we must express this distance in arc or angular measure. This is readily done if the observer has previously determined the arcual value of one revolution of the screw in the following manner. Having separated the wires by a convenient number of revolutions, say ten, the time in seconds occupied by a star on the celestial equator in passing from one wire to the other is noted.[1] Dividing this number by ten, we get the time corresponding to one turn of the screw. As one second of time corresponds to fifteen seconds of arc, we multiply the time determined for one turn of the screw by fifteen to get the value in angular measure for each turn of the screw.

55. **Velocity of Light.**—*Methods of Fizeau and Foucault.*—In 1849 M. Fizeau determined the velocity of light on the earth's surface according to the method described in the following quotation from Glazebrook's 'Physical Optics': 'L and L′ (fig. 45) are two telescopes at a considerable distance apart, directed to look into each other, with their axes parallel. At the focus of L′ is a plane mirror, M, at right angles to the axes of the telescopes, while between the object-glass and focus of L is a plane piece

[1] To obtain the interval in equatorial seconds of other stars, it is necessary to multiply the observed *time* by the cosine of the star's declination.

of glass, G, inclined at an angle of 45° to the axis. I is a bright source of light, the rays from which pass through an aperture in the tube of the telescope L, and fall on the glass G; they are there reflected along the axis, and I is so placed that its image, formed by reflection from the glass G, coincides exactly with the focus of the telescope L. The rays then emerge from its object-glass parallel to the axis, and after traversing the distance L L′, which, in Fizeau's experiment, was 8,663 mètres, fall on the object-glass of L′, and are refracted by it to its principal focus.

There they are incident on the plane mirror M, and being reflected by it, emerge again from L′ as a parallel pencil of rays, and, passing through the first telescope L, produce on the eye of the observer E the impression of a bright star of light at M. R is a toothed wheel which revolves about an axis parallel to that of the telescopes, and is so adjusted that as it turns its teeth pass directly between the image of I, formed by the glass G and the mirror M. As each tooth in succession crosses the axis of the telescope L, the light reflected from G is intercepted by it and prevented from reaching M, while the return beam from M is also intercepted and prevented from reaching the eye. Let us suppose that the breadth of each tooth is equal to the distance between two consecutive teeth. If the wheel be moving somewhat slowly, as each space between two teeth begins to cross the axis

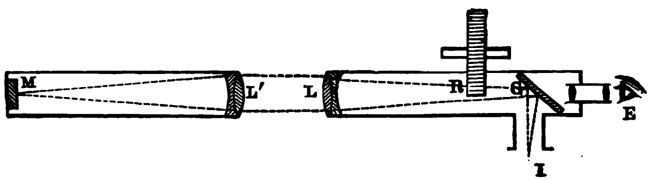

FIG. 45.

of L, the light will pass through, and after reflection at the mirror M will arrive back at the wheel before the whole space has crossed; it will thus reach the eye, and the star M will be visible. Suppose now that the rate of rotation of the wheel is increased. Then it may happen that by the time the light reflected from M again arrives at R a tooth is crossing the axis, and in this case the return beam is stopped and the star of light is eclipsed.

This will happen if the velocity of the tooth be such that it passes through its own breadth in the time occupied by the light in travelling from L to M and back.

If we double the velocity, by the time that the return beam reaches R the space next to the one through which the light passed will be crossing its path, and we shall see the star bright through this; while with a treble velocity there will be an eclipse again, and so on.

Now, in Fizeau's experiments the wheel had 720 teeth, and the first eclipse took place when the wheel turned 12·6 times per second. Thus the time required to turn through the width of a tooth was $\frac{1}{2} \times \frac{1}{720} \times \frac{1}{12 \cdot 6}$ of a second, and this is equal to $\frac{1}{18144}$ of a second.

But in this time the light has travelled twice the distance between M and the wheel, that is, through $2 \times 8,663$, or 17,326 mètres. Thus the

velocity of light is 17,326 × 18,144 mètres per second, and this, when multiplied out, is rather greater than 314,000,000 mètres per second.

A similar experiment was carried out by Cornu with more perfect apparatus, and he obtained a result of 300,400,000 mètres (186,663 miles) per second.

Another method, depending on an application of the principle of the rotating mirror, was introduced by Foucault. As improved by Captain Michelson, this method is illustrated in fig. 46.

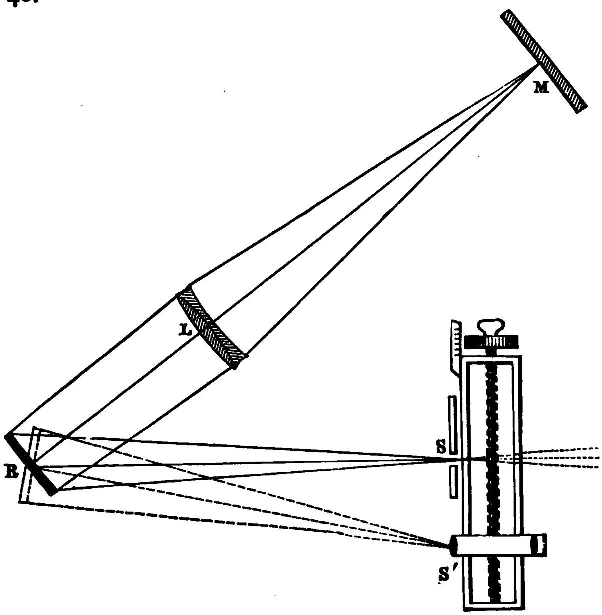

FIG. 46.

Through a slit, S, light passes to the plane mirror R, which is capable of rotating about an axis in its own plane. L is an achromatic lens placed at its own focal length from R. Some of the light reflected from R passes through the lens and forms an image of the slit on another plane mirror placed at M. A portion of the light falling on M is again reflected, and, passing again through the lens to R, *returns to* S, forming there another image

of the slit. If the mirror R be now made to rotate rapidly in the direction of the hands of a watch, the image of the slit will no longer return to S; for the pencil reflected from M finds the plane mirror R on its return in the position indicated by the dotted line, and the image of the slit is consequently displaced from S to S′. By measuring the amount of this displacement S S′, the distances S R and R M, and the rate of rotation of the mirror, the velocity of light can be calculated. Michelson's determination shows that light travels in a vacuum with a velocity of 186,330 miles per second.

CHAPTER IV.

SPECTRUM ANALYSIS.

56. **The Prism.**—For optical purposes a prism may be described as a wedge-shaped piece of glass or other transparent medium with polished surfaces; or it may be defined as a solid body bounded by five plane surfaces, two of which are triangles forming the ends, and three of which are quadrilaterals forming the inclined sides and the base. The triangles are generally parallel and equal, and the quadrilaterals are usually rectangles. A section of such a prism by a plane perpendicular to the inclined faces therefore shows an equilateral triangle as in the figure. The section, however, of some prisms gives a right-angled or isosceles triangle. The glass lustres of a chandelier

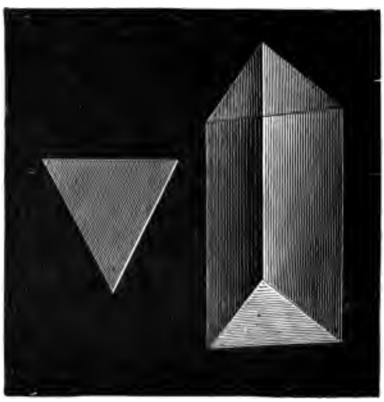

FIG. 47.—The Prism.

are usually examples of prisms. Prisms may be formed of any transparent substances. Solid bodies can always be cut into the shape of a prism, and fluid substances can be put into this shape by confining them in hollow prisms of glass. We proceed to explain the action of a prism on the light that falls on one of its surfaces.

57. **Refraction of Monochromatic Light by a Prism.**—Let A B C, fig. 48, represent the section of a prism standing on its base. Let a ray D *e* of light of *one particular colour* fall on the surface A B. On entering the glass this ray is bent towards the perpendicular *f e* in the direction *e h*. After passing through the prism in a straight course it is again bent at *h*, on emerging into the air away from the perpendicular *g h* in the direction *h* E. Had there been no prism in its path the ray D *e* would have passed along the straight course D D_1. At whatever angle the incident ray may fall upon the surface A B, it is deflected from its original course in such a way that the emergent ray is bent from the refracting edge or towards that surface of the prism (the base) through which it does not pass, provided the substance of the prism is denser or has a greater refractive index than the medium in which the prism is placed. The edge A opposite the base C B is called the *refracting edge*. The solid angle B A C is called the *refracting angle*, and the angle formed by the emergent ray *h* E with the straight course D D_1 of the incident ray is called the *angle of deviation*. By rotating a prism slowly on its axis the emergent beam of light will be found to be bent in different degrees from its original path; but in the particular case illustrated in the figure the incident ray D *e* forms the same angle with the surface A B that the emergent ray E *h* forms with the surface A C. The path taken

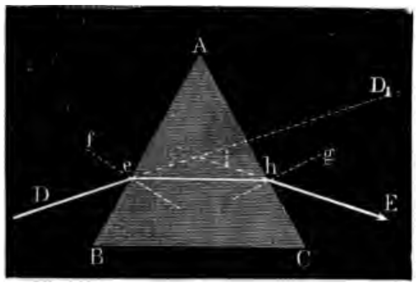

FIG. 48.—Path of a Ray of Light through a Prism.

by the ray in this case is called the ***symmetrical path*** of a ray, and this position of the prism is called the position of least or *minimum deviation*, the angle formed by the emergent ray h E with the course D D_1 of the incident ray being in this case the *angle of minimum deviation.*

58. **Decomposition of White Light.**—In the preceding experiment we have supposed the light to be of one colour—yellow or red, for example. But when the *white* light from the sun or any other source is sent through a prism, it not only undergoes refraction, but it is decomposed into several kinds of light. This decomposition of white light into its various colours is termed the *dispersion* of light, and is due to the

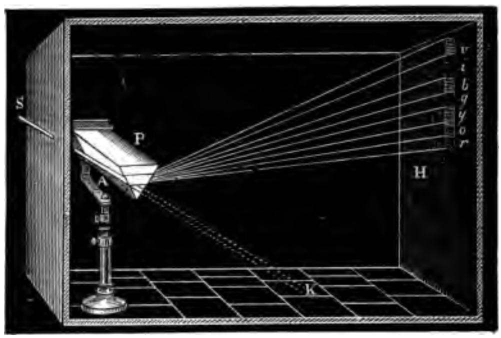

FIG. 49.

unequal refraction of the various rays constituting white light. If a ray of sunlight be allowed to pass through a small hole in the shutter of a darkened room, as is shown in fig. 49, there will appear a round white spot of light in the direction of the rays on the floor at K. But if a flint-glass prism with its base horizontal be allowed to intercept the rays, the beam after being refracted in passing through the prism is separated into various coloured rays, and there is produced on a distant screen a rainbow-coloured band, which is called the *solar spectrum*, or the *prismatic spectrum*. In this brilliant band the colours gradually blend into one another. At the end lying nearest the incident beam we have a dark *red*, which gradually passes into *orange*;

range again blends into *yellow*; the yellow into *green*; reen into *blue*; this is followed by *indigo*; and finally there *let*. These are known as the seven colours of the spec- . On looking at No. 1 of the coloured plate it will be that these colours show varieties of tint and pass into one ner by imperceptible gradations, so that there are really than seven. This experiment clearly proves that white is compounded of innumerable coloured rays; that these are bent out of their course in different degrees on passing igh a prism (*i.e.* have different degrees of refrangibility); that when combined together do they produce on the retina of ye the impression we call whiteness. As each ray is differ- affected by passing through the prism, we are then able e each one in its own special and peculiar hue. We thus

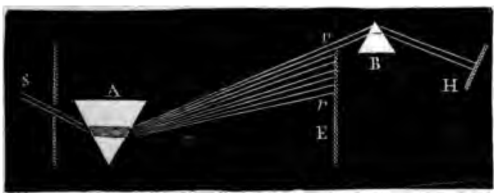

FIG. 50.

the important truths that rays that differ in colour differ in refrangibility, and that the rays towards the red end of spectrum may be called the less refrangible rays, and the towards the violet end of the spectrum are the more ngible rays. If one of the colours of the spectrum be ted by allowing it to pass through a hole in the screen, it be received on another prism, as in fig. 50, and the rays allowed to pass will be further dispersed, but no new urs will be produced. This shows that the colours of the rum are simple or indecomposable, and that the red rays, xample, do not consist of one single tint of red, but are osed of various shades of red, each shade being differ- refrangible. We also see that light which has suffered rsion by one prism may be further dispersed by a second 1. We also find on experimenting with prisms formed of

various substances, that the colours always succeed one another in the same order, viz. beginning with the least refrangible, *red, orange, yellow, green, blue, indigo, and violet*, but that the various coloured spaces do not always occupy the same proportional lengths of the spectrum. Thus the spectrum formed by a prism of flint glass is nearly three times as long as the spectrum formed by a prism of water of the same refracting angle, though the various coloured parts of the spectrum are not equally enlarged. The length of the spectrum also depends on the refracting angle of the prism, increasing nearly in proportion as this increases up to a certain limit. Again, the length changes with the angle which the incident rays make with the surface of the prism on which they fall; but it is usual to adopt as the standard position for the prism that in which the rays on passing through undergo minimum deviation.

59. **Recomposition of the Colours of the Spectrum.**—If white light is composed of the various colours of the spectrum, then by the recombination

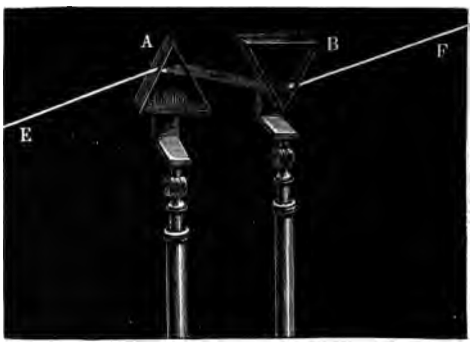

FIG. 51.—Neutralisation of Refraction and Dispersion.

of these colours white will be reproduced. This recomposition may be effected in several ways. If the spectrum be allowed to fall on a double convex lens a *white* image of the sun will be formed on a screen placed at a distance equal to the focal length of the lens; or if the spectrum produced by one prism be allowed to fall on another prism of similar composition and equal refracting angle, but inverted, the incident beam will be refracted and dispersed by the first prism, A, but the second prism, B, refracts in the opposite direction, and re-unites the coloured rays into the colourless beam F, parallel with the incident beam E. Fig. 51.

60. Purity of the Solar Spectrum.—The spectrum formed by admitting light through a small hole really consists of coloured images of the hole, so that if the slit is wide these images overlap and produce indistinctness and confusion of colours. To obtain a pure spectrum we must have a very narrow slit of less than $\frac{1}{100}$ inch in width, and it is also necessary to render the divergent rays of light passing through the slit parallel, that they may fall on the prism at the same angle. This latter requirement is effected by interposing a converging lens in such a position that the rays on reaching the first surface of the prism are brought to parallelism. The lens used for this purpose is known as a *collimating lens* (par. 62). On receiving these parallel rays on a prism placed in the position of minimum deviation they suffer refraction and dispersion, and the emergent beam gives a pure spectrum consisting of images of the slit ranged side by side. This image may either be received on a screen, or it may be viewed directly by an eye placed at a suitable distance in the path of the emergent rays.

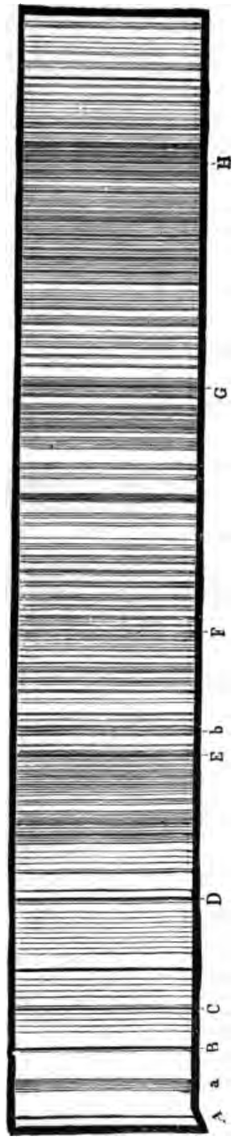

FIG. 52.—Fraunhofer's Solar Spectrum.

61. Fraunhofer Lines of the Solar Spectrum.—Newton first discovered the composite nature of white light by showing the action of a prism on a solar beam admitted through a hole in a shutter, as already explained. But in his experiments the light was allowed to pass either through a round hole, or through a hole shaped like a parallelogram 'a tenth or a twentieth of an inch broad.' Now this width of slit is far too great to show us all that may be learned by examining the solar spectrum, as there is overlapping of the images that form the spectrum owing to the light coming through different parts of the holes. About

a century later, Wollaston admitted the light through a much finer slit, and allowed it to fall on a prism so placed that the edge of the refracting angle was parallel to the slit. On placing his eye behind the prism so as to view the spectrum directly, he found that the solar spectrum was not a continuous band of light, but that it was crossed ***at right angles to its length*** by dark lines showing spaces where certain rays are absent. But it was not till 1814 that these dark lines were carefully examined. In that year a celebrated German optician, Fraunhofer, published a minute description of them, accompanied by a map showing 576 of these lines. This number has been greatly increased by other observers, and now amounts to several thousands.

Fig. 52 is a reduced copy of his map. The lines are of various widths, but many of them are as fine as the finest

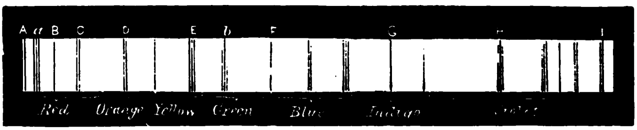

FIG. 53.—The principal Dark Lines in the Prismatic Spectrum.

spider's web, so that the portion which is filled with light is much greater than the portion filled with these dark spaces. (See Coloured Plate, No. 11.) Fraunhofer used the letters of the alphabet to designate some of the chief lines, beginning with A in the red and passing on to H in the violet. We add a smaller figure (fig. 53), showing the chief Fraunhofer lines of the solar spectrum, the white spaces being supposed to be occupied by the colours indicated beneath, and shown in the solar spectrum of the coloured plate already referred to.

As reference is frequently made to the lines as here lettered, the student should render himself familiar with their position by drawing fig. 53 until he can reproduce it without the book. A is a strong line *close* to the red end of the spectrum, and near it is a group of several lines marked *a*. Sir David Brewster thus describes the position of the others: 'B lies in the *red* space, near its outer end; C, which is broad and black, is beyond the middle of the *red*; D is in the *orange*, and is a strong double line, easily seen, the two lines being nearly of the same size, and separated by a bright

space; E is in the *green*, and consists of several, the middle one being the strongest; F is in the *blue*, and is a very strong line; G is in the *indigo*, and H in the *violet*.' Remembering that the spectrum consists of a series of fine images of the narrow slit through which the sunlight is received, we now clearly understand that the dark lines are gaps in the spectrum indicating the absence of rays of certain refrangibilities from beams of solar light. The red portion of the spectrum consists of a series of images side by side of the differently refrangible red rays, and the dark lines in the red portion indicate that certain red rays are wanting, and that their images do not appear. It is the same with the other portions of the spectrum. Moreover, Fraunhofer showed that these dark lines are present in all kinds of sunlight. They are seen when the direct sunlight is allowed to fall through a fine slit on a prism in the way already described, and they are also seen when reflected sunlight, as from the clouds, the moon, or the planets, is suitably examined. On examining the spectra produced by light from the fixed stars, Fraunhofer found that each star produced a spectrum showing the prismatic colours and containing dark lines, but most of these stellar spectra differed both from the solar spectrum and from each other in the number and position of the dark lines. This observation was important, for it proved that the cause of the lines seen in the solar spectrum and not in the fixed stars could neither lie in our own atmosphere nor in general space, but must lie somewhere in the neighbourhood of the sun itself. Some of the lines, however, he perceived to be due to our atmosphere, as they appeared distinct and dark in the spectrum of the sun when it was observed near the horizon, but grew faint when the sun was on the meridian. Thus the thickness of the atmospheric layer through which the light passed had some effect on the solar spectrum; but, as just intimated, the great majority of the dark lines are due to other causes.

62. **The Spectroscope.**—Before proceeding to describe further the various kinds of spectra we will give a brief account

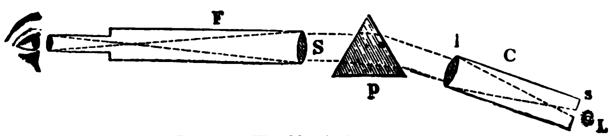

FIG. 54.—The Simple Spectroscope.

of the instrument now generally used to produce and examine spectra. Such a spectrum apparatus is called a spectroscope, and the mode of resolving light by means of it is called spectrum analysis. In its simplest form it consists of three parts: (1) a tube C, called the *collimator*, having a narrow slit at one end and an achromatic converging lens for rendering the rays parallel at the other (the slit is of parallel metallic jaws, the width of which is adjusted by a fine screw); (2) a prism, P, for refracting and dispersing the light; (3) a telescope, F, of

moderate power for magnifying and examining the spectrum produced by the action of the prism.

The various parts will be understood from figure 54. The rays from the source of light, L, passing through the slit of the collimator are rendered parallel by the lens at the other end. These parallel rays falling on the prism, usually placed in the position of least deviation for the central yellow rays, undergo refraction and decomposition. The spectrum, S, thus formed is brought to a focus in the telescope F, so that the observer

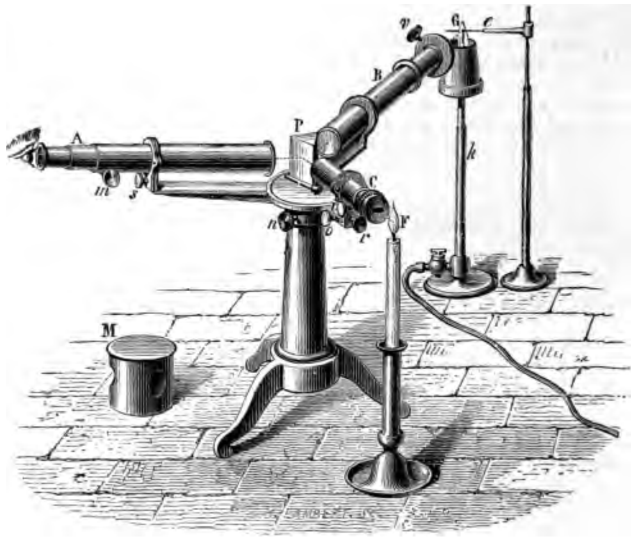

FIG. 55.

sees a magnified image of this spectrum on looking through the eye-piece. All light except that under examination must be shut off from the prism, either by enclosing it in a tube or by covering it with a dark cloth. In order to measure the relative distances of the lines in a spectrum, a third telescope is often used in connection with a spectroscope. Such an instrument of three telescopes is shown in fig. 55. The eye of the spectator is placed in the axis of the telescope A, which is directed to that surface of the prism from which the dispersed

light proceeds to form the spectrum. It is focussed by the milled-headed screw *m*. The opposite surface of the prism receives the parallel rays that are formed on passing through the slit and the collimating lens of the tube B. The screw *v* regulates the width of the slit through which the light passes. The telescope C contains the photographic negative on glass of a finely divided scale which is illuminated by the lamp or candle F. The light from this candle passes through the scale, and, being reflected from the surface of the prism P through the object-glass of the telescope A, the observer sees at the same time the spectrum and the scale, and is thus able to measure the relative distances of the various lines in the spectrum. M is a metal cap for covering the prism so as to exclude extraneous light. In this figure the observer is supposed to be looking at the spectrum formed when a platinum wire, *e*, dipped in a volatilisable salt, is held in the colourless flame G of the Bunsen burner *k*. Instead of an illuminated scale a micrometer eye-piece is sometimes used for the purpose of measuring the distance between two lines in the spectrum. The number of turns of the screw required to bring the cross wire or needle-point from coincidence with one line to coincidence with the other furnishes a measure of the distance required.

Various other forms of spectroscope are in use, some of them being very complicated and expensive. In order to increase the dispersion of the light under examination, compound spectroscopes with more than one prism are often employed. The dispersion is increased by each prism, as many as ten being sometimes employed, and the spectrum seen in the telescope is thus greatly lengthened. By this increase of dispersion not only is the spectrum made larger but lines are seen which would otherwise be missed and lines which are very close together and seem to be but one may often be shown to be separate by higher dispersive power. Thus the solar line D can be shown to be made of two distinct lines when the dispersion is sufficiently great. Kirchhoff, who first explained the real meaning of the dark lines of the solar spectrum, used an instrument in which four prisms were employed (fig. 56). 'These four prisms were cemented on to small brass tripods and placed on a flat iron table. They could thus easily be adjusted to the minimum deviation for every ray under investigation. The tube A, which was directed towards the sun, carried the slit with the comparison prism; the telescope B, which received from the last prism the widely diverging rays of the solar spectrum, could be moved by means of a micrometer screw, R, on a divided circle, so as to determine the distance between any of the dark lines in angular measure.'

The *comparison prism* is used when the spectra of two flames are to be examined *simultaneously. It is* a small right-angled prism placed over

either the upper or lower half of the slit. Fig. 57 will serve to illustrate its action. F is the source of light from which rays pass directly through the slit to form a spectrum in the way already explained. The other source of light, L, is a flame in which another substance may be volatilised so as to form a spectrum for comparison with the one formed by the flame F. The rays from the flame L fall at right angles on the first face, *d f*, of the comparison prism, and, being totally reflected from the opposite face, *d e*, leave the prism by the third face, thus entering the slit of the collimator to form a second spectrum in juxtaposition to the first. These two spectra *o* and *u* may be either viewed by another telescope or received on a screen, and the coincidence or non-coincidence of any of their lines ascertained. For producing some of the metallic spectra, it is sufficient to

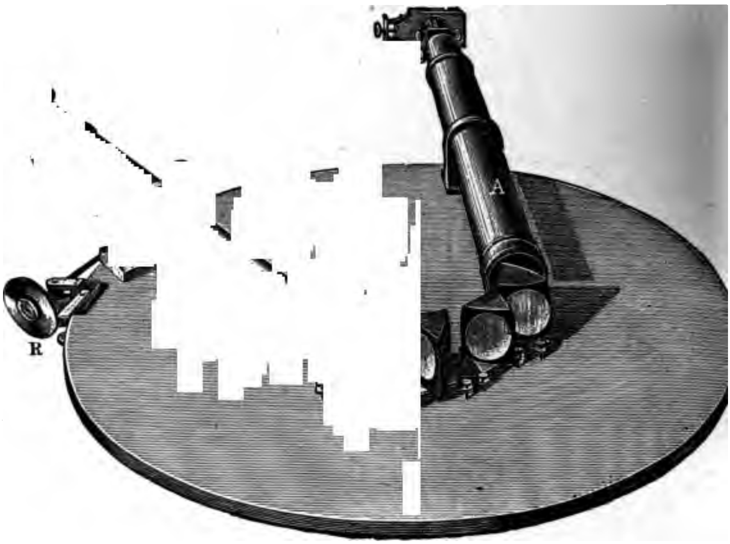

FIG. 56.—Kirchhoff's Spectroscope.

dip platinum wires in solutions of their compounds with chlorine and hold these wires in a Bunsen burner, or the wicks of candles may be saturated with these compounds. It has long been known that the salts of certain metals colour the non-luminous flame of a Bunsen burner with a colour depending on the metallic base of the salt. Thus, salts of sodium give a yellow flame; of potassium, a violet; of barium, a green; of strontium and lithium, a red. Examined by a spectroscope, these flames show distinctive bright lines, so that the red due to a salt of lithium can be easily distinguished from the red due to a salt of strontium, and thus the spectrum can be used as a test for the presence of the metal. (See fig. 60.) In the case of the alkali metals, K, Na, Li, there is sufficient reason to believe that the heat of the Bunsen flame decomposes the salt, and that the vapour

'hich gives the spectrum is the vapour of the metal itself. But with the lkaline earths Ba, Sr, Ca, the spectrum in the flame is rather the spectrum f a compound of the metal, for with the more intense heat of electricity he spectrum of narrow bands given by the flame with some salts of these ıetals is replaced by one of narrow bright lines due to the metal itself. 'he heavy metals as a rule show no spectra in the flame. It is thus vident that different degrees of heat are needed to obtain the spectra of he various classes of metals. How the high temperatures necessary to

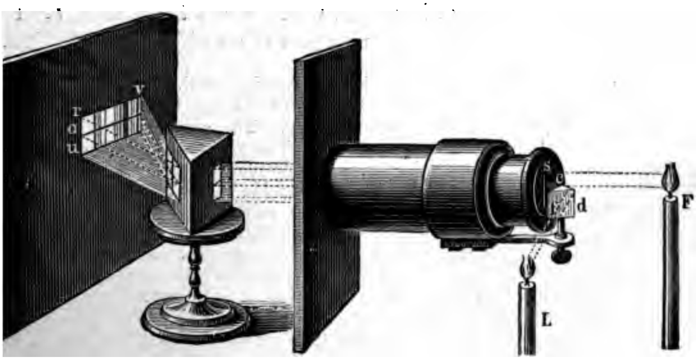

FIG. 57.—Two Spectra.

xhibit the spectra of some metallic vapours are obtained will be explained n a succeeding paragraph. Of the spectra of compounds we need only emark that they nearly always show fluted bands; that though it was nce supposed a compound gave the same spectrum as its elements, we now now that each compound has a spectrum of its own, and that there is no lecided relation yet made out between the spectrum of an element and the pectra of its compounds.

63. **The Pocket Spectroscope.**—For some purposes a simple ›ocket spectroscope may be used. Prisms may be so combined

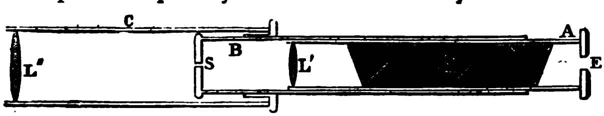

FIG. 58.—Convenient Form of Pocket Spectroscope

s to produce *dispersion* of the extreme rays without *deviation* of he central rays, and the light passing through a slit may thus ›e decomposed to produce a spectrum in the line of the incident ay continued. Such an arrangement forms a direct-vision pectroscope, as it can be held in a straight line between the

source of light and the observer's eye. A convenient form of direct-vision spectroscope is shown in fig. 58. The compound prism by which the light is dispersed is enclosed in the tube A. At one end of this tube is an opening, E, for the eye, and at the other end it is terminated by the lens L′. The tube A slides in a second tube, B, which carries the adjustable slit S. In some cases a third tube, C, is added, with a short focus lens, L,″ for throwing light from a particular part of an object on the slit S.

64. **The Telespectroscope.**—In astronomical work a spectroscope is so attached at the eye end of a telescope that the image formed by the object glass falls on the slit of the spectroscope. The combined telescope and spectroscope is called a *telespectroscope*. The plane of the slit coinciding with the real image formed by the object-glass, it is manifest that light from any part of the sun may be separately examined. As the image of a star in a large instrument is little more than a mere point, its spectrum would be a line only. To give some breadth to this line, a cylindrical lens is placed before the slit when examining stellar spectra. Any spectroscope, when used with a lens interposed between the luminous object and the slit so that light from various parts of the object may be thrown on a slit and separately examined, is sometimes spoken of as an *analysing spectroscope*. (See fig. 61.) When light is received from a luminous body as a whole, the instrument may be called an integrating spectroscope.

65. **Diffraction Spectra.**—A prism is not the only means of separating the variously coloured constituents of a compound ray of light. Spectra may be produced by *gratings* as well as by prisms. Such spectra are the result of what is known in optics as diffraction. The phenomena of diffraction are the effect of modifications which light undergoes on passing through very small apertures or over the sharp edge of a body. The coloured fringes seen round the shadows of bodies in sunlight are effects of diffraction. A diffraction grating consists of a number of very fine parallel lines ruled on the surface of glass or some bright metal so as to produce a large number of equal and equidistant small rectangular apertures. Gratings with 28,000 lines to the inch are often used, and Professor Rowland of Baltimore has constructed a machine that has ruled as many as 43,000 lines in an inch. When a finely ruled glass grating is placed in front of a slit or other bright line, with the scratches parallel to the slit, there is seen by an eye looking through it an image consisting of one central white band, with a succession of spectra on either side, all placed with the violet end towards the centre. By turning the eye to the right or left these spectra may be separately examined. The first spectrum on either side stands apart from the rest, but by looking in a direction more inclined to the perpendicular of the grating the other successive spectra may be seen, the red end of each overlapping the violet end of the preceding one. By proper means, however, any one can be isolated. The two first spectra are short and brilliant; the succeeding ones gradually increase in length, but diminish in brilliancy. These diffraction spectra are well adapted for determining the wave-lengths of the various coloured rays, as the distribution of the different rays in these spectra is in exact accordance with the length of the waves. This is not the case with the prismatic spectrum, as in it

there is unequal dispersion, the violet end being more extended than the red end.

66. The Heating and Chemical Effects of the Solar Spectrum.—Besides the visible spectrum confined within the limits of the lines A and H, it has been found that the spectrum extends on both sides far beyond the red and far beyond the violet. The infra-red portion of the spectrum contains the rays in the sun's beams which are less refrangible than the red rays, and which, though invisible, produce effects of heat. In the spectrum formed by a flint-glass prism it is found that the heating effect is chiefly confined to the red end, and that the maximum is even beyond the red. The light, on the other hand, has its greatest intensity in the yellow part of the spectrum

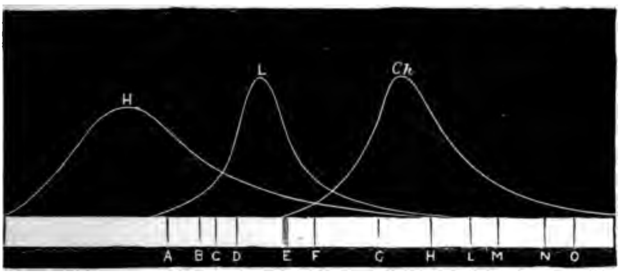

FIG. 59.—Illustrating the Distribution of Heat (H), Light (L), and Chemical (photographic) Activity (C *h*) in the Solar Spectrum (prismatic).

and its least in the violet part. But beyond the violet there are rays of high refrangibility in the spectrum which manifest their presence by chemical effects. The chemically active rays begin to be found at the end of the yellow part of the spectrum, and show themselves most active about the violet. But the ultra-violet portion contains for some distance these *actinic* rays, as they are often called. It is these chemically active rays that are chiefly used in the art of photography, for this art mainly consists in fixing images on substances sensitive to light. But by suitable means both the infra-red and the ultra-violet portions of the spectrum have been photographed. The photograph shows, in the ultra-violet, dark lines similar to the Fraunhofer lines, the chief of these being known as L, M, N, O, P It must

be clearly understood that the three different effects spoken of are not produced by three different rays, for the same ray may possess all three properties, and its effects depend on the nature of the objects that receive it.[1] Fig. 59 illustrates diagrammatically the various intensities of the light, heat, and chemical action in the various parts of the solar spectrum formed by a flint-glass prism, the curved lines indicating the various degrees of these actions, and the summit of the curve denoting the position of maximum effects in each case.

67. **Radiation or Emission Spectra.**—Various sources of light emit rays which, when directly examined by the spectroscope, give rise to various kinds of spectra.

(*a*) *Continuous Spectra.*—In the first place, it must be noticed that all solid and liquid bodies glowing with white heat emit rays which give rise to a spectrum that is without any break from the red to the violet. (See No. 1 of the Coloured Plate.) No lines or gaps are seen as in the sun's spectrum ; the coloured band is continuous. Such a spectrum is seen when we look with the spectroscope at glowing molten iron, at a white-hot platinum wire, or at the flame of an oil-lamp. (The flame of an oil-lamp or a candle contains white-hot particles of carbon.) This continuous spectrum of solid and liquid bodies is not of the same length for all degrees of heat. On heating a piece of platinum wire firmly fixed before the slit of the spectroscope by the non-luminous flame of a Bunsen burner, it glows at first with a dull red heat, and the red part of the spectrum only is seen. As the heat increases, the orange, yellow, green, blue, and violet parts of the spectrum are added in succession, until the whole continuous spectrum from the red to the violet is seen. At this time the metal appears white hot to the eye. Whatever solid or liquid is brought into a state of white heat, it gives a similar spectrum, so that we have, in short,

[1] 'In accordance with the impression produced upon our senses, we are accustomed to divide the solar rays into light, heat, and chemical action. These three different effects are not to be regarded as the results of three different kinds of rays, but rather as different effects inherent in the ether vibrations. According to the length of the waves and the nature of the receiving particles, this energy shows itself either as heat, light, or chemical action.'—*Schellen.*

the general rule, *All glowing solid and liquid bodies give a continuous spectrum.* It follows from this that as the spectra of all incandescent solid and liquid bodies are continuous, such a spectrum does not enable us to recognise the substance producing it. We can only conclude that it is most probably produced by a body in the solid or liquid state, emitting rays of all kinds.

(*b*) *Bright Line Spectra.*—But there is another kind of emission or radiation spectrum. Glowing gases and vapours give discontinuous spectra, consisting of coloured lines or bands on a dark ground. As these bright lines or bands are constant in position and, at any given temperature, in intensity also, it thus becomes possible by volatilising a substance to tell, from the bright lines yielded, what element it contains, and, to some extent, its physical condition also. Hence the study of the discontinuous spectra of vapours and gases forms an important part of spectrum analysis. The various metallic substances require different degrees of heat to turn them into vapour. Thus sodium is volatilised in the flame of a common spirit-lamp. If a little common salt, which is chloride of sodium, be placed on a clean knife and held in this flame, the flame becomes intensely yellow. On examining this yellow flame by the spectroscope in a darkened room where sunlight is shut off, a strong yellow line is seen in the instrument. With a spectroscope of good dispersion-power this line is seen to be double (see Coloured Plate No. 2). Even if the sunlight or the light from a lamp is admitted through the slit at the same time as the yellow light of the sodium flame, the sodiüm line can still be distinguished in the orange-yellow part of the spectrum. Many other metals, such as potassium, lithium, strontium, calcium, and barium, can be volatilised wholly or partially by heating their chlorides at the end of a clean platinum wire in the non-luminous hot point of a Bunsen burner, as explained in par. 62 (see fig. 60). On looking through the spectroscope, properly focussed, the characteristic coloured lines of each metal will be visible if the slit is sufficiently narrow to ensure their sharp definition.

The subjoined illustration shows the position of the chief lines of some of these metals, the solar spectrum and its lines

being indicated above for the sake of comparison. The colour of the lines may be inferred from their position in the spectrum. (See also the Coloured Plate.) When a substance shows more than one line, the various lines are designated, according to their degree of brightness, by affixing the Greek letters to the chemical symbol of the substance. Thus Kα denotes the brightest line in the spectrum of potassium. This is in the red portion of the spectrum. Kβ denotes the next brightest line,

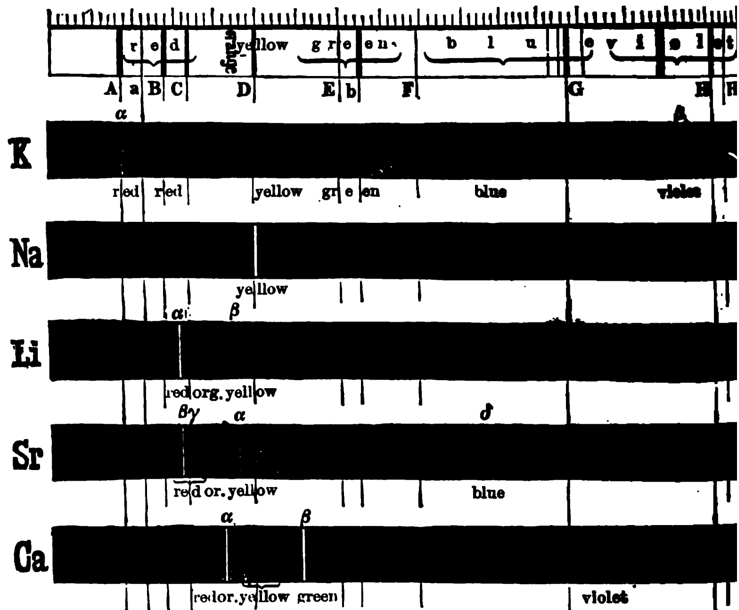

FIG. 60.

which is in the violet. (It will now be readily understood how easily the chemist can detect the presence of any of these metals by their distinctive lines. Very small portions of the substance make themselves thus manifest.[1] It was by spectroscopic

[1] Bunsen and Kirchhoff have calculated that the eighteen-millionth part of a grain of sodium can be detected by the spectroscope. So widely diffused is this element, that it is difficult to obtain a flame free from traces *of sodium vapour.*

analysis that several new elements—rubidium, cæsium, thallium, indium, and gallium—were first discovered.) But

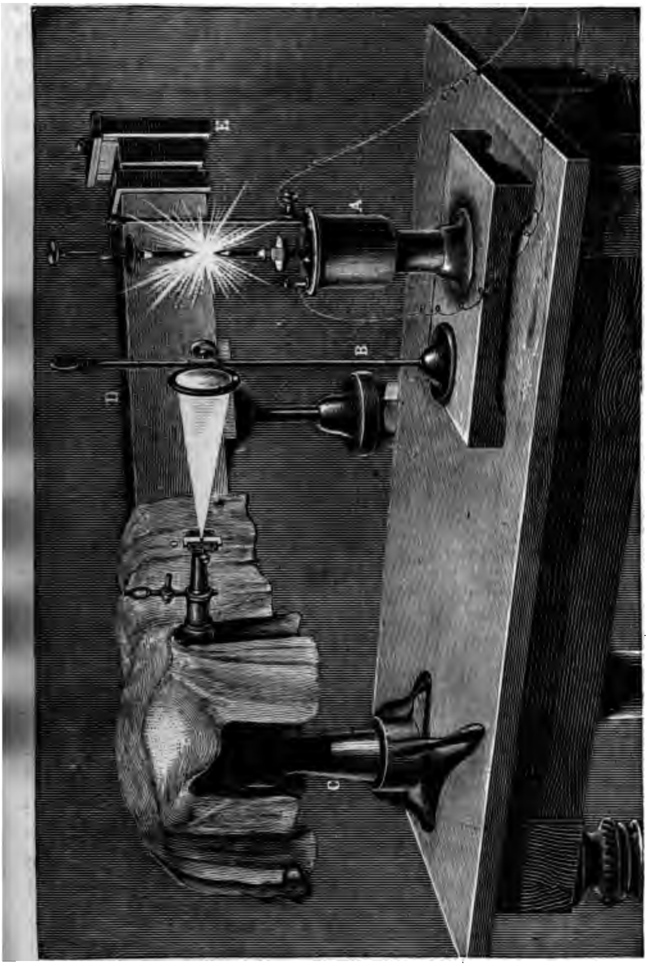

FIG. 61.—Lockyer's Apparatus for the Simultaneous Exhibition of the Spectra of Various Sources of Light.

the heat of the Bunsen burner is not sufficient to volatilise and decompose *some of the compounds.* A still greater heat can

be obtained by burning a mixture of oxygen and coal-gas brought from separate vessels to a suitable burner. When hydrogen and oxygen are used we get the oxyhydrogen flame, which is still hotter than the oxy-coal-gas flame. But for such metals as iron and nickel the heat produced by the electric arc or electric spark is needed. The voltaic arc is produced by the passage of an electric current between two rods of carbon which form the terminals of the poles of a battery. The electricity is generated either by a powerful battery or an electro-dynamic machine driven by steam. Such a machine converts mechanical power into electricity, and the electric current, in passing from one carbon rod to the other, produces an intense light. With pure carbon this light would give a continuous spectrum, associated to some extent with the spectrum of carbon vapour. By keeping the carbon points as far apart as possible, and placing the salts of the heavy metals on the lower one, the spectra produced by their metallic vapours may be seen. The spectra of iron, nickel, &c., may also be obtained by using metallic poles of these metals. These spectra will be complicated with the spectrum due to the air which has been rendered incandescent, but by examining at the same time two spectra from two pairs of metallic poles made of different materials the lines common to the two spectra may be recognised. These will either be air lines or lines due to some common impurity of the poles. Professor Lockyer, by the arrangement shown in fig. 61, has been able to photograph the spectra of the metals.

A photographic picture of a spectrum of a metal or of the sun gives us a perfectly truthful and permanent representation of what we only see for a short time when we look through the telescope. The sensitive plate furnishes us both with an accurate representation of the position of the lines, and marks their intensity and breadth. This it does not only in the visible portion of the spectrum, but also in the infra-red and ultra-violet portions. Moreover, it is quite possible to photograph the spectrum of the sun and of various metals on the same plate, one immediately below another, and thus to furnish a ready means of comparison. This is done by dividing the slit of the spectroscope into sections. A (fig. 61) is the

electric lamp for producing the light between carbon or metallic poles; B is a lens for throwing the image of the electric arc on the slit O. (By having the slit horizontal and the arc vertical a spectrum of various portions of the arc may be obtained.) The prisms for dispersing the light rest on the stand C, and are covered by a black cloth to shut out any side-light. D is the photographic camera, and E is the case containing the sensitive plate on which the photographic image is to be taken. By

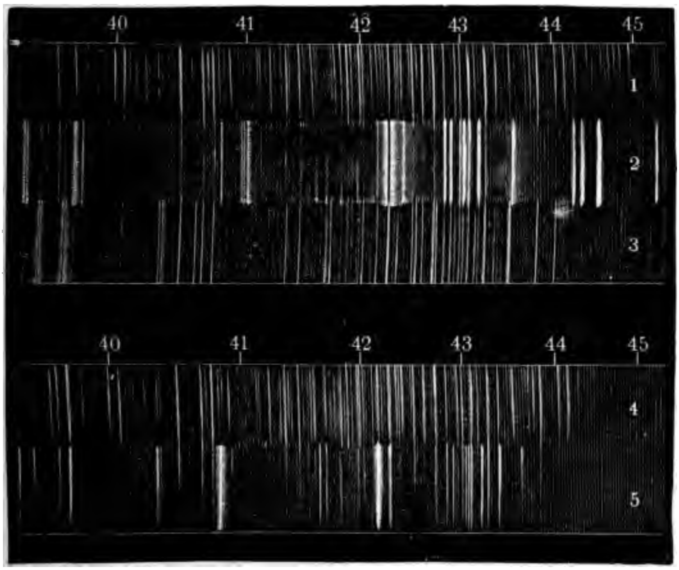

FIG. 62.—Photographed Spectra of Metals.
1. Spectrum of Meteorite. 2. Spectrum of Calcium. 3. Spectrum of Aluminium.
4. Spectrum of Iron. 5. Spectrum of Barium.

placing the bright-line spectra of metals in juxtaposition on the photographic plate Professor Lockyer was enabled to show that many lines that appeared to be coincident in some of the metals were due to a common impurity. Other lines that appeared to be coincident were shown not to be truly so on using spectroscopes with higher resolving power. A few of the coincidences *in the metallic* spectra still remain without

sufficient explanation. The bright-line spectrum of a metal observed in the electric arc is accompanied by the spectra of the gases (the air lines) through which the discharge takes place. Moreover, by the examination of the various sections of the arc some of the lines are seen to be very short, and confined to the neighbourhood of the poles, while others are long, stretching from pole to pole. These longest lines are not always the strongest, some of them being very weak. The longest lines are also always most persistent when the temperature and pressure are reduced. They may therefore be seen in cases where the short lines are invisible.

FIG. 63. Plücker Tube.

To obtain the radiation spectrum of the permanent gases—oxygen, hydrogen, nitrogen, &c. —a special tube, Geissler's or Plücker's, is employed. Plücker's tube, shown in the figure, has the central portion very narrow. By sending an electric discharge through such a tube containing the gas in a highly rarified state, it becomes luminous at a temperature far below that of incandescence. The colour of the electric discharge varies according to the nature of the gas, and when examined by the spectroscope, on placing the capillary portion of the tube before the slit, the light emitted shows the characteristic spectrum of the gas (see Coloured Plate No. 6).

68. **Variations of Spectra.**—The spectra of the various elements obtained by one or other of the methods above described consist of a larger or smaller number of bright lines, each substance yielding its distinctive and characteristic spectrum under similar conditions. The temperature at which the spectrum is produced has no influence on the relative position of the lines; but the ***number*** of the lines in a spectrum, as well as their relative intensities, may undergo considerable changes, not only by change of temperature, but also by change of pressure. Thus the spectrum of lithium in the Bunsen flame shows one bright red line only; at a higher temperature a faint orange line appears; while in the electric arc a bright blue band makes its appearance. Increase of pressure in some cases—for example, in hydrogen and sodium—may produce a widening of lines, the

lines being broader at high than at low pressures. In some gases, as hydrogen, oxygen, nitrogen, &c., two different spectra appear, a spectrum of the first order with shaded bands with an electric discharge of moderate tension, and a spectrum of another order, consisting of bright lines with dark spaces between, produced by a high-tension spark in Geissler tubes. Under certain conditions an incandescent gas may even give a continuous spectrum. At a very high pressure, when the density must be very great, hydrogen gives a continuous spectrum on receiving a powerful electric spark; while the spectrum of oxygen is continuous at the lowest temperature at which the gas is luminous. Though spectra are thus variable, it appears that for any one temperature or pressure each vapour has its own special spectrum of lines or bands, and that a spectrum of fluted bands usually belongs to a vapour which is colder than one which has a spectrum of bright lines. Professor Schuster says in the 'Encyclopædia Britannica': 'Spectra may be classified according to their general appearance. The different classes have been called orders by Plücker and Hittorf. At the highest temperature we always obtain spectra of lines which need no further description. At a lower temperature we often get spectra of channelled spaces or fluted bands. When seen in spectroscopes of small resolving power these seem made of bands which have a sharp boundary on one side and gradually fade away on the other. With the help of more perfect instruments it is found that each band is made up of a number of lines which lie closer and closer together as the sharp edge is approached. Occasionally the bands do not present a sharp edge at all, but are made up of a number of lines of equal intensity at nearly equal distances from each other. Continuous spectra, which need not necessarily extend through the whole range of the spectrum, form a third order, and appear generally at a lower temperature than either band or line spectrum. One and the same element may at different temperatures possess spectra of different orders. A discussion has naturally arisen as to the cause of these remarkable changes of spectra, and it is generally believed that they are due to differences of molecular structure.'

69. **Absorption Spectra.**—It has already been mentioned that when light passes through any medium it suffers more or less absorption. A glass thickly coated with soot completely absorbs the light falling upon it, while a slightly smoked glass diminishes the intensity of the light it transmits by effecting a partial absorption. Coloured glasses only transmit certain kinds of rays, for with them a selective absorption takes place. Thus a red glass only transmits the less refrangible rays, and absorbs the green, blue, and violet rays. It is thus seen that the colour of bodies generally results from the fact that a portion of white light falling upon them is absorbed. When the unabsorbed portions are transmitted through the substance, then the body is coloured and transparent, as are many varieties of glass, some liquids, and some vapours. When the

unabsorbed rays are reflected, then the body is coloured and opaque. Those which transmit or reflect all kinds of light rays are white ; those which transmit or reflect none are black. If sunlight or the white light from any incandescent solid be sent through any absorptive medium, we shall be best able to study the effects produced by this medium on the continuous spectrum if we examine the transmitted light by the spectroscope. Such transmitted light produces what is called an absorption spectrum, and the student must remember that when we speak of an absorption spectrum we mean a spectrum formed when white light has passed through an absorption medium. Our space will not allow us to say anything here about the absorption spectrum produced by various liquids.

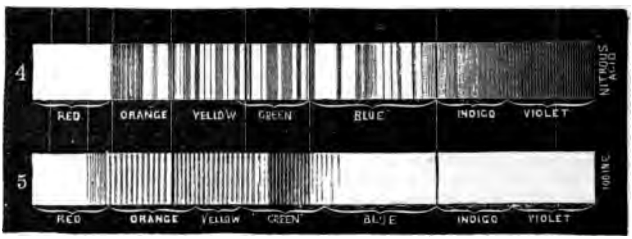

FIG. 64.—Spectra of Absorbent Substances.

Nor do these much concern us. But the absorptive action of gases and vapours is a matter of great importance to us. Many coloured gases and vapours give an absorption spectrum in which are seen dark lines or narrow black bands traversing the colours of the continuous spectrum. Thus if a spectroscope be arranged so that a good continuous spectrum becomes visible, on heating a few crystals of lead nitrate in a test-tube in front of the slit, the red vapour of nitrous acid (nitrogen tetroxide) is formed, and its absorption spectrum may be examined. Similarly, by heating a few crystals of iodine in a test-tube plugged with cotton-wool, the beautiful absorption spectrum of iodine vapour may be observed. Numerous fine lines will be seen in the orange and yellow, and a shaded band, really consisting of very fine lines, in the green.

Even some colourless gases, as aqueous vapour and oxygen, possess a power of selective absorption when a column of sufficient thickness is examined. The vapours of metals which when examined directly emit light producing bright-line spectra, also furnish absorption spectra of dark lines. Now it was long thought that there must be some close connection between the power of a body to emit light and the power of a body to absorb it. But for some time the nature of this connection remained unknown. However, the investigations of several distinguished men of science gradually established a very important relation between the emission and absorption of light. When considering the significance of the fact that the double bright line emitted by sodium vapour was coincident with the double dark line D of the solar spectrum, Professor Stokes, in 1852, offered the following explanation :—

'The light given out by an incandescent vapour depends upon the vibrations of its molecules, in the same way as the tone of a note of a piano depends upon the vibrations of the string. If a note is sounded in a room where there is a piano, it will be found that the strings answering to that note will respond by giving out the same tone. The same thing occurs with regard to light: when light passes through a vapour, the molecules of which have power to vibrate in any certain relationship, these are stimulated by the rays of light passing amongst them to vibrate in concert with them; but only such rays can transfer their vibrations to the gas molecules as are vibrating in unison with them. But in proportion as the light transmits to the gas molecules its own vibrations it loses energy itself, and becomes weakened or extinguished; but this can only occur in such rays as vibrate in coincidence with the gas molecules. It is evident that it depends entirely upon the nature of the vapour through which white light passes, which portions of the light will be lost, or, in other words, which colour will be weakened or absorbed by the vapour. When, for instance, white light passes through vapour of sodium, the only rays which will be weakened will be those corresponding to the two yellow lines of this vapour, and in contrast to the other rays they will appear dark.'

Kirchhoff, in 1860, at last put the relation between emission and absorption into a more definite form, which is spoken of as the 'law of exchanges.' This law asserts that *every substance which at a given temperature emits certain rays of light is capable at the same temperature of absorbing the same kind of rays that it emits.* It is important to notice the phrase 'at the same temperature'; for if the absorbing body is giving out light of the same quality as that which it absorbs, no effect will be percep-

tible ; if the absorbing body is giving out more light than it receives, it will produce its own effect in somewhat less degree; but if the absorbing body be at a lower temperature, so as to give out less light, then this absorbing body will so enfeeble the rays that it takes up that they will be wanting in the light that is transmitted. An incandescent body, therefore, which gives all kinds of radiations, and produces a continuous spectrum, on shining through a cooler gas or vapour has certain rays taken out, the absorbent vapour cutting out or refusing to allow to pass only those rays which it itself sends forth. Luminous

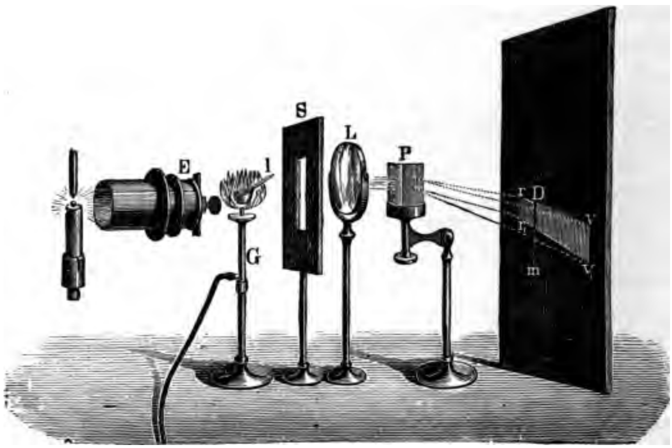

FIG. 65.—Reversal of the Sodium Line (projected on a Screen).

sodium vapour, as we have seen, burns with a yellow flame, and produces, under ordinary circumstances, a spectrum of a close pair of orange yellow lines. If intense white light from a glowing solid or liquid body be allowed to pass through the luminous sodium vapour, the vapour will abstract from the white rays just those yellow rays which it was emitting; the other rays—the red, orange, green, blue, and violet—passing through the sodium vapour with little diminution. If, then, the light which passes the sodium vapour be examined by the spectroscope, a close pair of dark lines will be seen on a background of continuous spectrum, and these dark lines will occupy exactly the same position as

the two bright lines of the emission spectrum given by sodium vapour (see Coloured Plate). The sodium lines are said to have been *reversed*. To show the reversal of the sodium line the apparatus seen in the figure may be employed. We first get the bright-line spectrum of sodium by removing the parts G and S and allowing the light from the electric lamp (the poles of which have been moistened with a solution of sodium chloride) to pass through the prism and form a continuous spectrum. In this spectrum the bright sodium line will be seen, and its position may be marked by the letter *m*. In a short time the sodium on the carbon points is all evaporated. A small piece of sodium is now burnt in a platinum spoon in the Bunsen burner G, the perforated screen S being placed before the lens L to protect the large screen from the yellow light of the burning sodium. The sodium ignites and forms a cloud of vapour in the path of the rays from the electric light, and there appears on the screen the dark line D, exactly in the same place as the bright line *m* appeared. There is thus produced the absorption spectrum of sodium. In a similar manner, the bright lines of the emission spectra of potassium, lithium, calcium, barium, iron, and other metals have been reversed; that is, their characteristic *bright* lines are changed into *dark* lines when the intense white light of the sun or other incandescent solid or liquid body passes through the cooler vapours of these metals. Thus the dark lines in a spectrum are not produced by the source of light but by the screen of relatively cooler vapours that comes between the light source and the spectroscope.

70. Explanation of the Fraunhofer Lines.—We are now in a position to understand what effect a less heated atmosphere of vapours will exert on the more intense light which would produce a continuous spectrum. In such a case the spectroscope will show this continuous spectrum crossed by dark lines, and these dark lines will be the more numerous, the more complex this atmosphere is. If, then, we can establish a complete coincidence between the bright lines of the gaseous spectrum of a certain substance with the dark lines produced in an absorption or reversed spectrum, we may safely conclude that

this same substance is contained in the absorptive atmosphere which produces the dark lines. By producing a bright solar spectrum, and then bringing the glowing vapour of sodium in front of the slit, Kirchhoff showed that the dark D lines of the solar spectrum coincided exactly with the bright lines of the sodium vapour (fig. 66.) By means of the comparison prism these two spectra may be seen at once in the same instrument. From these observations Kirchhoff concluded that the dark lines D in the solar spectrum were produced by the bright light from the sun's nucleus shining through an atmosphere containing sodium. He next took a more complex spectrum, like that of iron. Arranging the spectroscope so as to have the two spectra one above the other, he found that the bright lines of the spectrum of iron were exactly matched in position by dark lines in the solar spectrum. By comparing the bright lines of other metallic spectra with the dark lines in the solar spectrum, Kirchhoff found that such metals as iron, calcium, and magnesium have dark representatives in the spectrum. If the sun's atmosphere contain the vapours of sodium, iron, calcium, and magnesium in a glowing state, then the white light from the incandescent mass beneath, on passing through these vapours, would produce the effects observed. Startling as the conclusion at first appears, that the atmospheric envelope of the sun contains glowing iron vapour, no other explanation can be given. To quote from a translation of Kirchhoff's own words : 'As this is the only assignable cause, the supposition appears to be a necessary one. These iron vapours might be contained either in the atmosphere of the sun or in that of the earth. But it is not easy to understand how our atmosphere can contain such a quantity of iron vapour as would produce the very distinct absorption lines which we see in the solar spectrum ; and this supposition is rendered still less probable by the fact that these lines do not appreciably alter when the sun approaches the horizon. It does not, on the other hand, seem at all unlikely, owing to the

FIG. 66.

high temperature which we must suppose the sun's atmosphere to possess, that such vapours should be present in it. Hence the observation of the solar spectrum appears to me to prove the presence of iron vapour in the solar atmosphere with as great a degree of certainty as we can attain in any question of physical science.'

Fig. 67 shows two portions of the solar spectrum, one situated in the yellow, between 120 and 126 of Kirchhoff's scale; the other in the green, between 150 and 154. The corresponding portions of the combined spectra of the glowing vapours of iron and calcium of the iron spectrum (Fe) are seen to coincide exactly with thirteen dark lines in the solar spectrum,

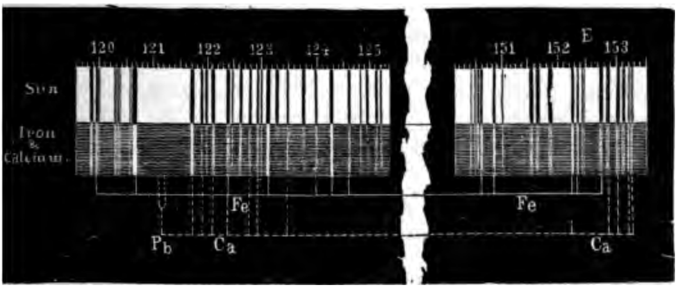

FIG. 67.—Coincidence of the Fraunhofer Lines with the Lines of Iron and Calcium.

while twelve bright lines, indicated by the dotted lines below, belong to calcium, and these also coincide with an equal number of dark lines in the solar spectrum. Kirchhoff showed about 60 bright lines of iron to be coincident in position with as many Fraunhofer lines, but since his time the number of coincidences has been raised to more than 460. Not only so, but in general the artificial bright lines of iron that appear strong when an electric discharge is passed between electrodes of the metal have dark solar lines corresponding both in position and intensity. The coincidences of the bright lines of other metals with dark lines in the solar spectrum have led to a fuller knowledge of the elements present in the vaporous envelope of the sun. The list given by Kirchhoff consisted of sodium, iron, calcium, magnesium, nickel, barium, copper,

zinc. Two other workers at this subject, Angström and Thalén, added chromium, cobalt, hydrogen, manganese, and titanium. Professor Lockyer, taking account of the facts that in the voltaic arc the cooler vapour of a metal in front of the hotter often produced a reversal of the longest lines of the metal when the short bright ones were not affected, and that these longest lines are found in that part of the arc where the vapour must be least dense, argued that if an element is not present in the sun in sufficient quantity to have all its lines reversed, it may indicate its presence by the reversal of its longest lines only. He therefore added to the above a number of elements the longest lines of which were found to coincide with Fraunhofer lines, and which therefore possibly exist in the sun's atmosphere in smaller quantity and at a lower pressure. Lockyer's addition includes aluminium, strontium, lead, cadmium, cerium, uranium, potassium, vanadium, palladium, and molybdenum. Some investigators would add carbon to the lists, but its spectrum is so peculiar, consisting of bands rather than lines, that there is still some little doubt about it.

Such evidence is held to prove that the body of the sun, the white surface of which we see, and which is known as the *photosphere*, is surrounded by an atmosphere of intensely heated, but still, when compared with the photosphere, relatively cooler vapours; that these vapours of themselves are capable of giving spectra showing their characteristic bright lines; and that therefore by absorption they give rise to corresponding dark lines in what would otherwise be the continuous spectrum of the more heated photosphere. As to the extent of this atmosphere, and the state of the vapours composing it, more will be said in the next chapter.

71. **Telluric Lines.**—While many of the dark lines in the solar spectrum have been shown to be due to the presence of certain metallic vapours in the sun's atmosphere, it has also been found that some are produced by absorption in our own atmosphere. Certain lines are observed to be faint at noon, and to get thicker and darker when the sun is near the horizon. Janssen, a celebrated French physicist, clearly proved in 1866 that most of these atmospheric lines are really due to aqueous vapour. This he did by examining the spectrum of a large gas-flame after the light had passed through 118 feet of steam enclosed in a tube. The steam caused various groups of lines to appear in the otherwise continuous spectrum, these lines being the same as those which were strengthened at sunset. The influence

of the weather on these lines is distinctly apparent, for in a moist atmosphere they are more strongly marked than during a cold dry wind. There is a particular group of these atmospheric lines which appears in small spectroscopes as a dark band lying on the red side of the D lines. In dry weather this band is indistinct, but before rain the band becomes considerably stronger. Hence it is known as 'the rain band,' and may be used as a means of prognosticating the weather. Quite recently Janssen has also been able to prove, what had before been surmised, that the Fraunhofer lines A, B, and *a* are due to the absorptive action of the oxygen in our atmosphere.

This he did by examining the solar spectrum at a great altitude on the side of Mont Blanc. The much smaller amount of atmosphere at this height so much enfeebled these lines as to leave little doubt that they would disappear could the influence of the atmosphere be wholly eliminated. A later experiment, made at night by passing the electric light from the Eiffel tower to the observatory at Meudon, showed that these lines were introduced into the spectrum of this light by the fourteen miles of atmosphere through which the beam passed. Messrs. Liveing and Dewar have recently examined the absorption spectrum of oxygen under high pressure in steel tubes, and have obtained the oxygen lines and bands quite clearly. It thus appears that light passing through a thick stratum of a colourless gas may be subject to selective absorption.

It may be well to remind the student that the solar spectrum, seen in a powerful instrument, furnishes several thousand dark lines, and that many of these have not yet been fully accounted for.

72. **Wave-lengths of Light Rays.**—In speaking of any particular part of the spectrum we may refer it to one of the well-known Fraunhofer lines, or to the number on Kirchhoff's scale. In constructing his map of the solar spectrum Kirchhoff referred to the various lines by numbers based on the arbitrary scale which he adopted; a scale, therefore, dependent on the construction of the instrument which he used. But the most exact way is to give the actual wave-length[1] of the ray of the light about which we are speaking. As this is a natural number, independent of the kind of instrument used, lines are now usually so given in modern discussions. The wave-lengths of numerous rays in the solar spectrum, as well as the wave-lengths of the rays corresponding to certain Fraunhofer lines, have been calculated with great accuracy by means of diffraction gratings. Angström constructed a map of the solar spectrum from A to H in which every ray is noted in its absolute wave-length. To this he applied the term 'normal solar spectrum.' These wave-lengths are exceedingly small. Expressed

[1] According to the undulatory hypothesis the motions of the particles of ether in a ray of light are at right angles to the track of the ray, or the

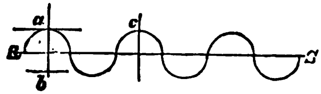

FIG. 68.

line in which the ray is advancing. Thus, in the figure, R S is the direction of a ray of light; the motion of the particles of ether is in the direction of *a b*; and the distance from one crest to another, as from *a* to *c*, is the length of the *wave*.

in millimètres, they may be given thus: For the ray corresponding to line B the length in millimètres = ·0006867; C = ·0006562; D′ = ·0005900; E = ·0005269; F = ·0004860, and so on for others. We may read these figures by saying that the wave-length of the line C is 6562 ten-millionths of a millimètre, or by leaving off the last decimal figure we may call the wave-length of C 656 millionths of a millimètre. It is usual, however, to express wave-lengths in ten-millionths of a millimètre (sometimes called tenth-mètres, a tenth mètre being $\frac{1}{10^{10}}$ mètres). When we know the velocity of light V per second in any medium, and the wave-length λ of a given ray, the number of vibrations per second for any coloured ray may be found by dividing the velocity by the wave-length $n = \frac{V}{\lambda}$. The number of vibrations for each colour is constant. For the extreme red ray it is 392 billions, and for the extreme violet ray 757 billions. For the sake of brevity wave-lengths are usually expressed thus: λ 6562, or λ 656, according as the length is expressed in ten-millionths or millionths of a millimètre.

The following table—derived, with some alterations, from Vogel's 'Spectralanalyse'—will be found useful for reference, and gives the wave-lengths of some of the most important lines of the solar spectrum, and also indicates the substance whose glowing vapour furnishes the corresponding bright lines. A complete list of all the lines whose wave-lengths have been measured is given in Dr. W. M. Watts's 'Index of Spectra.' The student will find it useful to remember that the lines marked A, B, and *a* in the red are due to the absorptive action of the oxygen in our atmosphere; that the line C is the brightest line of hydrogen H *a*; that the two D lines in the orange-yellow are due to sodium; that the group of lines E contain several due to iron; that at *b*, in the middle of the green, are two or three lines ascribed to magnesium; that just where the green begins to have a blue tinge is F, the second line, Hβ, of hydrogen; that between F and G is the third hydrogen line Hγ; that at G and in its neighbourhood are several more lines due to iron; that between G and H is the fourth hydrogen line Hδ; and that the lines called H_1 and H_2 are both ascribed to calcium.

Table of the wave-lengths of the most important lines of the solar spectrum according to Angström and the scale of Kirchhoff, with remarks.

Fraunhofer lines	Wave-lengths in ten millionths of a millimètre according to Angström	Number according to the scale adopted by Kirchhoff	Intensity and breadth according to Kirchhoff	Terrestrial substance furnishing the same lines, and remarks
A	7604	4041	6	Due to the oxygen of the Earth's atmosphere
B	6867	5926	6*c*	Due to the oxygen of the Earth's atmosphere
C	6562·1	6941	6*c*	Corresponds to the strong red line of hydrogen, H *a*
	—	7115	—	
	—	7195	—	

Table of the wave-lengths, &c.—continued.

lines	Wave-lengths in ten millionths of a millimètre according to Angström	Number according to the scale adopted by Kirchhoff	Intensity and breadth according to Kirchhoff	Terrestrial substance furnishing the same lines, and remarks
	6191	8497	3 *c*	Iron
	6163	8639	5 *b*	Calcium
	6141	8743	4 *b*	Barium
	6136	8770	4 *c*	Iron
	6121	8849	4 *b*	Calcium, cobalt
	6102	8949	2 *c*	Calcium
D^1	5895·1	10028	6 *b*	Sodium
D^2	5889·1	10068	6 *b*	Sodium
	—	12004	—	
	5615	12073	5 *g*	Iron
	5455	13435	6 *c*	Iron
	5371	14216?	5 *b*	Iron
	5327	14630	5 *c*	Iron, double
E	5269·13	15227	6 *c*	Iron, double
	5273	15237	4 *d*	Iron
	5237	15696	5 *c*	Iron
	—	15775	—	
	5183	16341	6 *c*	Magnesium
b	5172	16488	6 *f*	Magnesium
	5168	16537	6 *b*	Iron, nickel
	5167	16556	6 *c*	Iron, magnesium
	4961	19610	4	Iron
	4895	20414	6 *b*	Iron, double
	4874	20666	5 *c*	Iron, double
F	4860·72	20800	6 *g*	The greenish blue line of hydrogen, Hβ
	4382·8	27212	6	Iron, very broad
	4340	27962	6	The dark blue line of hydrogen, Hγ
	4328	28219	6	Iron
G	4307·25	28544	6	Iron
	4275	—	—	Iron
	4262	—	—	Iron
	4229	—	—	Calcium, double
	4147	—	—	Iron, double
	4104	—	—	The high temperature violet line of hydrogen, Hδ
	4075	—	—	Iron, strong
	4066	—	—	Iron, strong
	4048	—	—	Iron, strong
H_1	3968·1	—	—	Calcium
H_2	3933	—	—	Calcium

73. **Some Difficulties of Spectrum Analysis.**—It appears from what has been said that spectrum analysis enables us to determine the chemical composition of matter when in a state of gas or vapour, and with such gases or vapour as are produced in our laboratory experiments there is no difficulty whatever in making this determination. But it must be borne in mind that the artificial variations in temperature and pressure that we can bring about are not likely to be co-extensive with the great range of variations that exist in connection with the sun and some of the other celestial bodies. There is, therefore, a difficulty in finding spectra to match completely those we obtain on submitting the light from those distant orbs to the action of our instruments, and it is not always easy to determine the amount and value of the correspondence between a celestial and a laboratory spectrum. Moreover, the spectrum of some of the heavenly bodies is a complex spectrum, being in part a continuous spectrum crossed by dark lines, and in part a spectrum of bright lines from vapours glowing with intensity of heat. Such a spectrum must come from an incandescent solid or liquid body which is surrounded by glowing vapours some of which are cooler and some of which are hotter than the hot body beneath. This kind of spectrum will consist of dark lines, bright lines, and strips of continuous spectrum, and to understand fully this spectrum is a matter of considerable difficulty. It is not always easy to say whether a narrow bright strip is due to a glowing gas, or is merely a part of the continuous spectrum between two absorption bands, or whether a narrow dark strip is dark absolutely through the cutting out of rays, or only dark relatively to the brighter parts on each side. Notwithstanding these difficulties, the powerful instruments now in use, and the extensive observations and experiments that are constantly being made, have enabled us to make much progress in interpreting the various spectra; and much information has been already gained about the chemical and physical constitution of the distant worlds. Some of this will be set before the reader in succeeding chapters.

74. **Summary of the Facts of Spectrum Analysis.**—A spectrum is simply the light proceeding from a body spread out or dispersed by refraction. This dispersion can be effected by sending a narrow beam of parallel rays through a prism placed in a suitable position, and depends on the fact that white light consists of a multitude of rays differing in colour, and the various tints of colours having different wave-lengths, and suffering unequal retardation in the denser medium of the prism, are consequently deflected from their course in different degrees. The longest and slowest vibrations (the red) undergo the least deviation, or are least refrangible, while the shortest and quickest vibrations (the violet) undergo the greatest deviation, or are most refrangible. There are two chief classes of spectra, Emission or Radiation Spectra and Absorption Spectra. *Emission Spectra* are produced by the light which is given out

or radiated by various glowing substances, and which proceeds directly to the prism. According to the physical condition of the radiating body, the emission spectrum produced is either a continuous band of colour of every tint (a continuous spectrum), or it is an interrupted spectrum consisting of bright-coloured lines on a dark background (a discontinuous spectrum).

Absorption Spectra are produced by white light passing through the relatively cooler vapours of various substances in its path to the prism. Such vapours sift out certain rays, so that these spectra show dark lines or bands on a bright background.

As the spectrum of every solid and liquid luminous body is a continuous band of colour, little information can be learnt from such a spectrum. When speaking of the spectrum of a metal, therefore, it must be understood that the spectrum of its vapour is meant. Spectroscopic Analysis is chiefly occupied by the quality of light emitted by substances when in a state of glowing vapour, or with the effect produced by such vapour when light from a hotter source passes through it. In a mixture of vapours each one produces its own separate effects, and for any one temperature each vapour has its own spectrum of lines or fluted bands. Spectrum Analysis is thus a method of analysing the light proceeding from any source so as to ascertain what rays are present and what rays are absent, and thus to learn the chemical composition and physical state of the radiating or absorbing substances. The following numbered statements embody the main facts set forth in this chapter. Their fuller application to the sun and the other heavenly bodies will be explained in the sequel.

1. All incandescent solid and liquid bodies give a continuous spectrum, *i.e.* a spectrum in which all kinds of rays are present, and in which the band of colour shows no dark lines or gaps. Such a band really consists of a multitude of images of the slit of the spectroscope ranged side by side without any break.

2. Glowing gases and vapours, on the other hand, generally give a discontinuous spectrum made up of bright-coloured lines

on a dark background. The same substance under similar conditions (and often under different conditions) gives the same set of bright lines, and as these lines are characteristic for each substance, and as each substance, when two or more are present, produces its own spectrum independent of the other, an inspection of a bright-line spectrum may teach us the chemical composition of the glowing vapour or vapours that produce the spectrum.

3. Alteration of pressure and temperature often produces distinctive changes in the spectra of gases. Increase of pressure usually leads to a widening of the lines, while, under some circumstances of temperature and pressure, the spectrum of a gas consists of a number of bands, sharply defined on one side but gradually fading away on the other. Under a very high pressure, the spectrum of a gas may be continuous. Hence a spectrum may teach us not only what substance we are investigating, but it may also give us information as to the state of the substance with reference to temperature and pressure. In general, a spectrum of fluted bands proceeds from a vapour which is cooler than a vapour giving a spectrum of fine bright lines. Line spectra show variations in the relative intensities of their lines, and new lines are often brought out at high temperatures.

4. To observe the emission spectra given by some of the heavy metals such as those in the iron group, the high temperature produced by the electric arc or spark is required. The metal thus volatilised gives its spectrum of bright lines along with those due to the incandescence of the components of the air. The spectrum of a metal thus produced furnishes us with *long* and *short* bright lines, the short lines being confined to the hottest portions of the arc, and the long lines stretching right across the field. These long lines are the most persistent, as the temperature or the quantity of the substance is reduced.

5. The light reflected from an opaque body gives the same spectrum as it would have given before reflection; but if the opaque body be surrounded by an atmosphere of gases (as some of the planets), the reflected light may show dark lines added by the absorption of this atmosphere.

6. If light be reflected from a body that is itself luminous, the spectrum formed will be compounded of the reflected light and the light from the luminous body.

7. Each gas or vapour absorbs, from white light passing through it, just those rays of which its own spectrum consists, provided the gas or vapour is at a lower temperature than the body emitting the white light. The spectrum of white light which has thus been transmitted through a gas or gases is a ***reversed*** or ***absorption*** spectrum, and exhibits dark lines coinciding exactly in position with the bright lines of the absorbing substances.

8. The spectrum of sunlight, taken as a whole, is an absorption spectrum, consisting of a band of colour from red to violet, crossed by numerous dark lines known as Fraunhofer lines, the highly-heated vapours surrounding the more intensely white-hot surface of the sun, each absorbing the vibrations that beat in unison with its own from the continuous spectrum of the white light which would be produced in the absence of these vapours. In this way we can account for a large number of those dark lines in the solar spectrum which are not produced by the absorptive action of the gases of our own atmosphere. The coincidences of these dark lines with the bright lines of the spectra of certain metals, as seen when the solar spectrum and the metallic spectrum are placed side by side, or as ascertained by measuring the wave-lengths of these lines, are so striking as to lead us to infer the presence of the following elements somewhere in the sun's atmosphere.

Elements certainly present in the sun, as first shown by Kirchhoff, Angström, and Thalén.	Sodium, Iron, Calcium, Magnesium, Nickel, Barium, Hydrogen, Copper, Chromium, Cobalt, Manganese, Titanium.
Elements whose longest lines certainly coincide with Fraunhofer lines, as shown by Lockyer.	Aluminium, Strontium, Lead, Cadmium, Cerium, Uranium, Potassium, Vanadium, Palladium, Molybdenum.

9. Slight displacements in the position of certain lines in a spectrum have been used to indicate motions of approach to,

or recess from, the earth; a displacement of a line towards the violet end of the spectrum signifying approach, and a displacement of a line towards the red signifying recess.

We thus see that spectrum analysis is a method of analysing the light proceeding from any source, so as to ascertain what rays are present and what rays are absent, and thus to learn the nature of the body emitting the bright rays, as well as the nature of the absorbing substances through which the rays from the light source have passed before reaching the spectroscope. A beam of light of extra-terrestrial origin may therefore be compared to a telegram from a distant world, informing us of the elements that compose it, of the changes taking place in it, of the vapours by which it is surrounded, and of the motions that hurry it through space.

CHAPTER V.

THE PHYSICAL AND CHEMICAL CONSTITUTION OF THE SUN.

75. To the inhabitants of the earth and to those of the other planets, if there be any, the sun is the most magnificent, as well as the most important, object in the universe. All the planets move in their orbits under the influence of its attraction, and from its rays is derived the energy which produces every form of motion on their surfaces, whether manifested in lifeless matter or in living organisms, excepting only the greater part of tidal action and the activities due to internal heat. ('El. Phys.' 43.) Yet the sun is but one of the countless stars of the vast universe, one of those self-luminous bodies which consist of a mass of incandescent vapour sheathed in photospheric clouds.

76. **Distance and Dimensions of the Sun.**—In a later chapter will be explained the methods by which the *mean* distance of the sun from the earth has been found to be 92,890,000 miles. That this distance is variable is proved by the variations *of its apparent* diameter when accurate measurements are made

f this at different times of the year. About July 1st the pparent diameter is least, $31' \ 31''$, and about Dec. 31st the pparent diameter is greatest, $32' \ 35{\cdot}6''$. Hence we conclude hat the earth's orbit is not a perfect circle, and that the sun is nost distant from the earth on the first date and nearest at he later date; for we cannot suppose the sun's magnitude has such a periodic variation. Its mean apparent diameter may be taken at $32' 0{\cdot}05''$. Having ascertained the distance of the sun and its apparent diameter we find its real diameter to be 866,500 miles, $109\frac{1}{2}$ times the diameter of the earth; one second at the sun corresponding to 450·35 miles. Since the surfaces of spheres are proportional to the *squares* of their radii, the surface of the sun exceeds that of the earth in the ratio of $(109{\cdot}5)^2$ to 1^2; that is its surface is nearly 12,000 times the surface of the earth. The *volumes* of spheres are in proportion to the *cubes* of their radii, and the cube of 109·5 is about 1,300,000. Thus the volume of the sun occupies more than a million times the space occupied by the matter of the earth, so that, were the earth placed in the centre of the sun, the orbit of the moon would extend but little beyond half-way to the circumference of the sun. But though the *volume* of the sun exceeds that of the earth 1,300,000 times, yet its *mass*, or the quantity of matter contained in it, is only 332,000 times that of the earth. How the mass of the sun is found is explained n Chapter XIII. We see that the density of the sun must be much less than that of the earth. If we divide its mass, as compared with the earth, by its volume, as compared with the earth, we get the fraction ·255. Hence the sun's density is only about *one quarter* of the earth's density. To find its *specific gravity*, or density compared with water, we multiply ·255 by 5·5, the earth's density with water as the unit, and this gives 1·44, showing that the sun is not quite $1\frac{1}{2}$ times as heavy as water. To compare the force of gravity on the surface of the sun with the same force at the surface of the earth, we must divide its mass compared with the earth, 332,000, by the square of its radius, $109\frac{1}{2}$, and from this we learn that its superficial gravity is 27·6 times that of the earth. This means that a body would weigh on the surface of the sun 27·6 times what it weighs

on the surface of the earth, and would fall in one second 27·6 times the distance it falls in the same time on the earth—that is, 27·6 times 16 feet in the first second.

The estimate of the sun's density given above, 1·44, compared with water, is based upon its volume as given by the diameter of the photosphere, the bright disc usually regarded as its exterior surface. Professor Lockyer includes in its volume the extensive layers of the sun's atmosphere which he believes to exist outside the photosphere. An atmosphere of 100,000 miles would nearly double the volume, and, the mass remaining the same, would reduce the density by one-half. By taking in the corona as belonging to the sun's atmosphere, and assuming its height to be half a million miles above the photosphere, Professor Lockyer increases its volume ten times, and the density is reduced to one-tenth of the figures given above.

77. **General Idea of the Physical Nature of the Sun.**—Before proceeding to describe the various parts of the sun it will be advisable to obtain some general notion of the body we are about to study. Fig. 69, which is merely a diagram and not a drawing, will assist the reader in conceiving of its various parts.

1. *The Photosphere.*—The bright luminous surface seen by the eye or visible in a telescope is known as the photosphere, a word which simply means 'sphere of light.' The body of the sun is generally thought to be of a gaseous nature, though the gases forming the body must have a far higher degree of consistence than those known on the earth, while the photosphere is regarded as a radiant shell of cloud-like structure 'formed by condensation into little drops and crystals (like the water-drops and crystals in our terrestrial clouds) of certain substances which within the central mass of the sun exist in a gaseous form.' The photosphere seen in the telescope shows a mottled or granulated appearance in all places where it is not occupied by the relatively dark *spots*, or by the brighter streaks known as *faculæ*.

2. *The Chromosphere and Prominences.*—Just outside the photosphere is a comparatively shallow envelope of gases which rise here and there into prominences of various shapes. This envelope is known as the *chromosphere*, or 'sphere of colour,' because when seen at the time of a total eclipse, it appears in tints of pink and scarlet. Though the chromosphere and its *prominences* are invisible even to the telescope, except during

a total eclipse, owing to the overpowering illumination of our own atmosphere, yet its form and extent can be studied at all times by means of the spectroscope.

3. *The Corona.*—Invisible in the telescope, and unrecognised by the spectroscope, except during a total eclipse, there exists

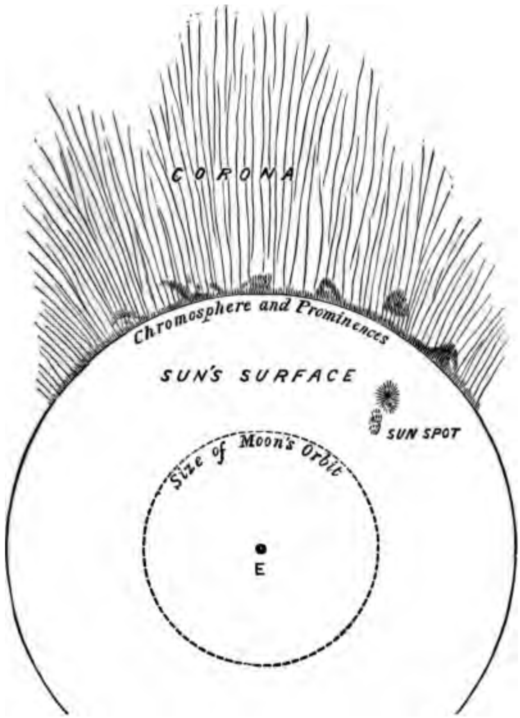

FIG. 69.

above the chromosphere another far more extensive envelope known as the *corona.* When the dark body of the moon shuts off the light of the photosphere at the time of a total solar eclipse, the corona is seen as a bright white halo or aureole of light surrounding the eclipsed sun. We will now consider these various parts—the *photosphere* with its spots and faculæ, the

chromosphere with its prominences, and the mysterious corona —in more detail.

78. **The Photosphere.**—When the eye is suitably protected from the intense light and heat of the sun, its surface may be examined directly through the telescope, or, by projecting the sun's image upon a suitable screen firmly fixed at the proper distance behind the eye-piece of the telescope, the image may be viewed by the unassisted eye. Photography has also been

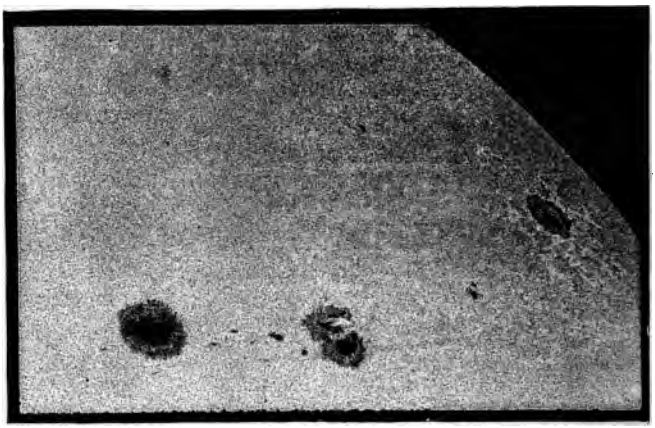

FIG. 70. From a Photograph by Warren de la Rue. Photosphere with Faculæ shown round the Spot near the Limb.

used with great advantage in solar studies, a picture of the surface being obtained by a proper instrument in a small fraction of a second. With a telescope of low magnifying power, the sun's surface looks like rough drawing-paper, while in more powerful instruments the photosphere appears to be made up of luminous masses on a darker background, like snowflakes on grey cloth. These brighter portions are of irregular shape, nearly as broad as long, and are known as 'nodules,' 'dots,' 'granules,' 'rice grains,' 'granulations,' &c. The photographs of M. Janssen show the texture of the sun's photosphere at the moment of exposure very satisfactorily. An examination of such a photograph proves that the luminous parts consist of brilliant

granules or cloudlets with darker spaces intervening. From this we see, leaving aside the larger spots, that the luminous surface is not continuous. In fig. 71 it will be noticed that some parts appear blurred, and in a photograph of the whole solar disc this network of hazy areas produces an appearance known as the 'photospheric network.' They are regions where the bright clouds that form the granules are situated somewhat lower than in the other parts. The granules or more brilliant parts of the photosphere are believed to consist of clouds forming the dome-like

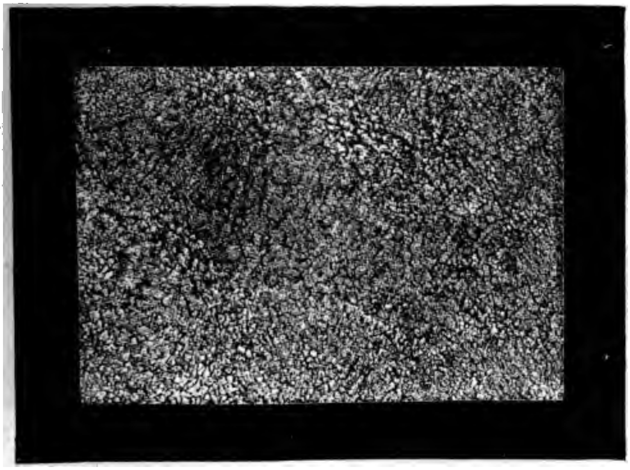

FIG. 71.—A portion of the Sun's Surface, showing the 'Solar Granules.' Photographed by Janssen, 1877.

ends of ascending and condensing currents of highly heated vapours, and the dark interstices or 'pores' between them possibly indicate descending cooler material. It should be noticed that the brightness of the sun's disc is nearly three times greater at the middle than near the edge or limb. This diminution of luminosity may be readily noted by observing the sun through smoked glasses, and is even more markedly seen in photographs of the whole disc. It is doubtless produced by the absorbent action of the sun's own atmosphere, as the light from near the edge of the disc will pass on its way to us through a greater

thickness of this atmosphere. Without this atmospheric absorption the disc would be of uniform brightness in all parts, like that of the moon. The bright streaks called 'faculæ' (Lat. *facula*, a torch) are best seen near the edge of the photosphere. They are really elevations of various shapes, produced by the aggregation of a number of the granules of the photosphere so that they form the highest and brightest parts of the photosphere. They are most frequent in the neighbourhood of spots, and most conspicuous towards the edge of the sun. As they are also, generally speaking, most abundant when the spots are most numerous, there appears to be some association between the two phenomena. Their development, however, always follows that of the spots.

79. **Sun Spots.**—The bright photospheric clouds appear to form the upper parts of a luminous sea of incandescent particles—a sea agitated by violent storms, full of mighty currents, ascending and descending, and at times torn open by violent explosions. Such rents in the bright surface give rise to the relatively dark patches known as spots. A fully formed spot, before it has begun to break up, is sometimes spoken of as a normal sun-spot. Such a spot, as may be seen in fig. 72, exhibits a somewhat rounded dark central portion called the *umbra*, fringed by a less dark border with bright filaments directed radially, called the *penumbra*. The blackest portion of the umbra near the middle is spoken of as the *nucleus*. Such spots, however, are rare, for most of them are of irregular shape, being often grouped together so that the umbra appears crossed by bright streaks proceeding from the photosphere termed 'bridges.' A spot begins from a mere point, rapidly increases in size, generally develops its penumbra after the nucleus, frequently begins to break up in a short time, the

FIG. 72.—Solar Spot with Radial Furrows in the Penumbra, and Bridges in the Nucleus.

segmentation being usually effected by a bridge, and finally disappears through the inflowing of faculous matter from the photosphere. Sometimes a new spot breaks out in the place where one has but just disappeared. The penumbra seems to consist of granules of photospheric matter lengthened out and drawn into the dark umbra. This appearance has been likened to 'thatch straws.' Spots are of various sizes, the umbra alone varying from 1,000 miles to 50,000 miles. Fig. 73 shows a spot whose diameter was four and a half times that of the earth.

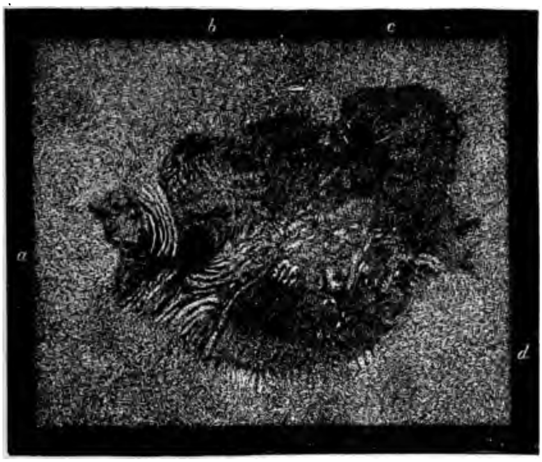

FIG. 73. - Solar Spot of July 30, 1865. (After Secchi.)

'In the midst of this chaos four centres of motion seemed to be distinguishable. To the left, at *a*, there appeared a wide gaping chasm, around which tongues of flame were entwined in various directions. In the upper part, at *b*, was a second centre, smaller than the first, which was sharply defined at the upper edge, and at the lower edge was similarly bordered by a multitude of flaming tongues. To the right, at *c*, yawned a wide rift in the form of an *s*, over which stretched tongues of fire, and loose fragments of luminous matter. Finally, in the lower part, on a level with *d*, was another elongated and convoluted chasm, the confused turmoil of which defies description. In

the part central to these four cavities was gathered a mass of faculæ and fiery matter, having the appearance of a boiling

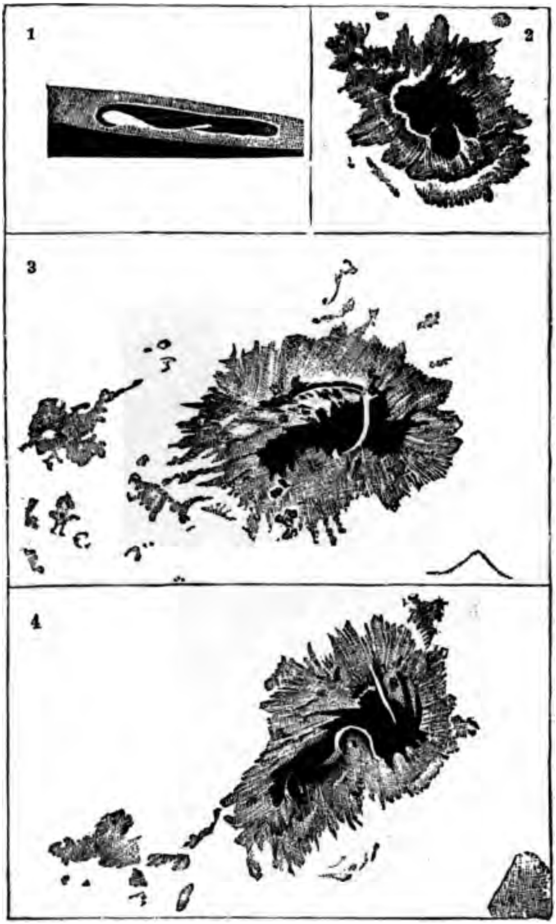

FIG. 74.—The Great Solar Spot of 1865 (from October 7 to October 16).

cauldron. Everything connected with the spot was in a state of stormy and tumultuous movement.'—Secchi. The great changes that often take place in a solar spot are well illustrated

he four drawings of a large spot of more than 40,000 miles area, that was carefully watched in 1865. No. 1 shows its n on first appearing at the eastern or left limb of the sun. s there seen of an elongated form, surrounded by a bright ;e of faculæ. In No. 2 it has moved nearer the centre, and umbra and penumbra are both well marked. On Octo- 14 a nearly central view was obtained, and a well-marked dge had formed across the nucleus. Further changes are n in No. 4, which was drawn two days later.

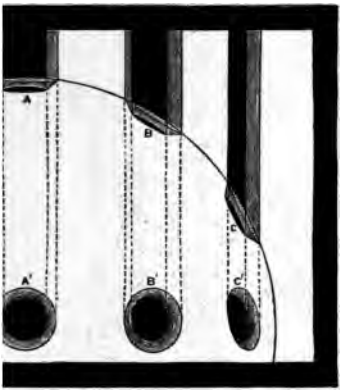

FIG. 75.—Showing that the Spots are Depressions.

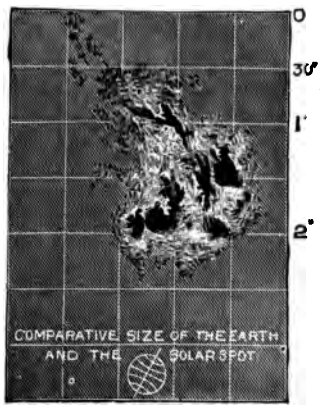

FIG. 76.—The great Solar Spot of April 19, 1882, 3.30 P.M. Extreme length, 2′ 0″. Mean breadth, 0′ 45″. ∴ Area, about 1,093,500,000 square miles.

The same spot may sometimes be observed to begin on the eastern limb, nove right across the disc and disappear on the western side, and to ppear on the eastern limb in the course of about fourteen days, passing oss a second time during the lapse of another fourteen days. This phe- nenon proves not only that the spots are connected with the surface of sun, but that the sun revolves round an axis. The average time taken a spot in setting out from a certain position and returning to the same :e is $27\frac{1}{4}$ days. By making allowance for the distance moved over by earth in its orbit during this interval, the true time of the sun's rotation been found to be 25·35 days. The curious fact, however, must be ed, that the time of rotation varies with the latitude of the spot, being ;t at the sun's equator and two days longer in latitude 40° N. or S. This ears to show that the sun does not, like the solid earth, rotate as one :e. That the spots are openings or cavities in the photosphere, and not, ome observers have supposed, elevations above the general surface, ears evident from the perspective effects observed. As a spot moves n the centre towards the western side, owing to the rotation of the sun,

its penumbra gradually contracts on the side next the centre of the disc, and expands on the side next the limb, the contracting inner penumbra finally disappearing as the spot passes off the western limb. These effects can only be explained on the supposition that the spots are saucer-shaped depressions, and that the sloping sides are formed by the penumbral filaments. Occasionally, too, the spots are seen on the limb as notches or indentations in the photosphere, a further proof that it is situated at a lower level than the general bright surface. As mentioned above, the spots, besides being carried round by the sun's rotation, seem to have a *proper* motion of their own, those near the sun's equator moving more rapidly than those in higher latitudes, and some changing their latitude in a few days.

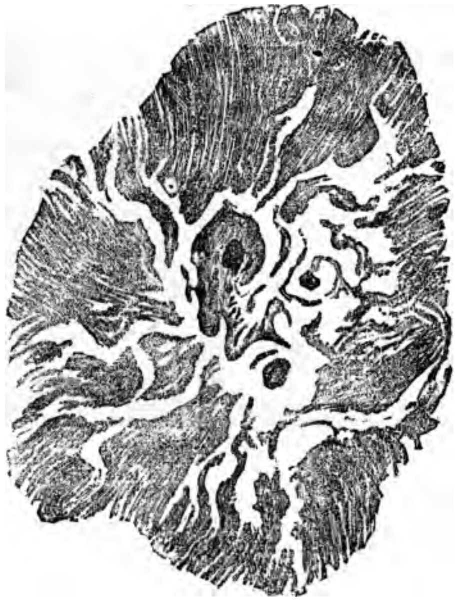

FIG. 77.—Faculæ round a Sun Spot (*Chacornac*).

80. **Origin of Sun-spots.**—Various theories or explanations have been put forward to account for the phenomena of sun-spots. That both eruptions from beneath and downpours from above occur in connection with sun-spots is undoubted, but it is not so easy to say which is cause and which effect. Secchi's theory regards solar spots as the result of internal convulsions which lead to eruptions in the photosphere, and, as a consequence, to a downpour of cooled and darkened vapours into the hollow thus produced. Describing this theory, Miss Clerke says, 'A sun-spot might then be described as a kind of inverted terrestrial volcano, in which the outburst of heated matter takes place on the borders instead of at the centre of the crater, while the cooled products gather in the centre instead of at the

border.' The great objection to this theory is that we do not find evidence to show that eruptions are the invariable commencements of the disturbances that originate spots, as this explanation requires. On the contrary, a dark speck is usually the first sign of the disturbance, while the faculæ, as before remarked, appear after the spot has fairly developed. This objection at least is obviated by Professor Lockyer's theory, expounded in his work on 'The Chemistry of the Sun.' He regards the solar coronal atmosphere as of great height, and supposes a system of circulation in this atmosphere by which vapours passing outwards and upwards from the photosphere, are at last brought down in condensing showers upon the luminous surface. This descent of cool material, part of which may be of meteoric origin, leads to the formation of the dark patches on the photosphere that indicate the beginning of a spot-disturbance. Moreover, the height of fall near the sun's equator is much greater than that near the poles, and hence the region of large spots does not reach beyond 35° N. and S., though pores and 'veiled spots,' which are similar phenomena on a smaller scale, are seen in all parts. M. Faye has a *cyclonic* theory, and regards spots as gigantic whirlpools. 'He believes that, owing to the fact that different zones of the sun rotate faster than others, whirlwinds analogous to our terrestrial cyclones, but on a vaster scale, are set in motion, and suck down the cooled vapours of the solar surface into the interior, to be heated and returned again, thus establishing a circulation which keeps the surface from cooling down.'

81. **Distribution of Sun-spots.**—Sun-spots are not distributed over all localities of the sun's disc, but are nearly confined to two zones on opposite sides of its equator and between the latitudes of 5° and 40°. A few are occasionally seen on and near the equator, but none beyond the latitude of 45°. The greatest number appear about latitude 15°, and there is a small excess in the northern hemisphere over those in the southern. If the sun's axis were perpendicular to the plane of the ecliptic, the spots, in traversing the sun's disc, would always describe a straight line, but the path usually appears to us more or less elliptical.

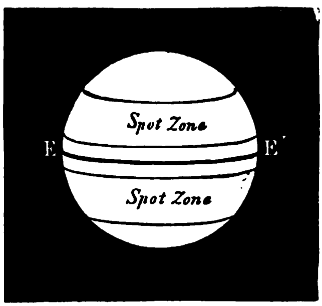

FIG. 78.—The Spot Zones on the surface of the Sun

The angle between the plane of the solar equator and the ecliptic has been found to be about 7°. Hence during one portion of the year its south pole is inclined towards the earth and

the spots describe oval paths with the convexity upwards, while during another portion of the year the north pole is inclined towards the earth, and the convexity of the oval paths is downwards. About the first weeks of June and December the plane of the solar equator passes through the earth, and the path of the spots becomes straight. Fig. 78 shows the spot-zones, and the true form of the apparent path in September.

82. **Spot-periods.**—Careful observation has clearly shown that spots are much more numerous at certain times than at others, and that there is a general round of time or *period*, from a minimum of spots, through a maximum to another minimum. This periodicity of sun-spots was first established by Schwabe of Dessau, who began his observations in 1826. After about twenty-five years of daily study he found that the spots ran through a cycle of growth and decay, in a period of time which was on the average about eleven years in length. This remarkable conclusion has been confirmed by other inquirers; 11·1 years being now given as the average. The subjoined figures will illustrate the above remarks, as well as show that the time of maximum is somewhat irregular, though it is always reached before the middle of the period. Thus the time from one maximum to another may vary from 10 to 12 years or even more. For the first period shown the number of spots is given, while for the second period the amount of spotted area in millionths of the sun's visible hemisphere has been estimated.

Year		No. of Spots	Mean Daily Number of Prominences	Year		Amount of Spotted Area	Mean Daily Number of Prominences
1867 min.	4 years	25		1878 min.	5 years	24	2
1868		101		1879		49	3
1869		198		1880		416	7
1870		305		1881		730	11
1871 max.	7 years	304	15	1882		1002	11
1872		292	12	1883 max.		1155	9
1873		215	9	1884	6 years	1079	11
1874		159	7	1885		811	10
1875		91	6	1886		381	7
1876		57	5	1887		179	9
1877		48	4	1888		89	8
				1889 min.		55	3

It thus appears that towards the close of 1889 there has been a minimum period; and we may therefore expect the next maximum spot-period to happen some time in the year 1893.

By erecting twelve parallel vertical lines and making their heights correspond to the number of the spots of each year, we may, by joining their extremities, obtain a curve representing this eleven-yearly period, and showing that the maximum is nearer the minimum preceding than the one following. During a year of maximum the sun is never a day free from spots, thirty or forty being often seen at once, while during a minimum many days may elapse without a single spot being visible. Another important fact regarding the spot distribution and period deserves notice. The solar activity which produces the spots formed in a sun-spot period commences about the time of minimum in two belts about 30° to 35° on each side of the sun's equator; then, multiplying a little in all parts of the spot-zone, they soon reach a maximum at about 15° N. and S., after which the mean latitude of the spots constantly diminishes and the disturbance dies out near the solar equator between + 5° and − 5°. Some two years, however, before its disappearance a fresh outbreak of spots has again begun in the high latitudes, so that at a time of minimum there are two distinct spotted areas in each hemisphere, the one near the equator belonging to the expiring period, and the one about latitude 35° belonging to the newly beginning period.

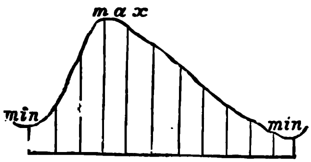

FIG. 79.

83. **Influence of Sun-spots on Terrestrial Phenomena.**—A close connection has been established between sun-spots and the magnetism of the earth. A magnetic needle freely moving in a horizontal plane does not point exactly to the north, but diverges from the geographical meridian by an amount which differs at different places. This deviation from the true north is known as the *declination or variation* of the needle. At present the declination at Greenwich is 17° 26′ W. But at any place this angle does not remain fixed, undergoing a change year after year. There is also a *diurnal* change of small amount, and it is with this that we are now concerned. The daily oscillation is of such a nature that the end of the needle which lies nearest the sun shows a slight tendency to direct itself towards this position, the north pole moving in our latitude every day from east to west a few seconds from sunrise to one o'clock, and then returning so as to reach its original position about 10 P.M., where it remains almost stationary till next morning. This small daily oscillation is greater in summer than in winter. Now the average amount of this daily oscillation at any fixed observatory increases and decreases as the amount of solar spots increases and decreases. This is clearly shown in the diagram, reduced from Flammarion's 'Astronomie Populaire,' the close correspondence in the upper curve of solar spottedness and the lower curve showing the diurnal magnetic variation making it impossible to doubt some kind of connection.

This connection is strengthened by another remarkable fact. Sudden and irregular disturbances of the magnetic needle occasionally occur, causing it to oscillate through several degrees in a short time. These 'magnetic storms' as they are called, have been found to be preceded or accompanied by sudden *changes in the condition* of the sun's surface, such as an outbreak

of sun-spots. Thus a remarkable magnetic storm was associated with a solar disturbance observed by Mr. Carrington in 1859 and also with the development of the great solar spot of April 1882. Magnetic needles and telegraph instruments were disturbed in various parts of the earth, and vivid auroras were seen in the skies, even in latitudes where they seldom appear. Indeed, curves of aurora frequently exhibit a close parallelism with the curves of magnetic disturbance and sun-spot frequency, all three phenomena showing an eleven-yearly period. Whether there is any connection or not with the earth's meteorology as exhibited in the weather, is a much disputed point. Some writers have endeavoured to establish the influence of

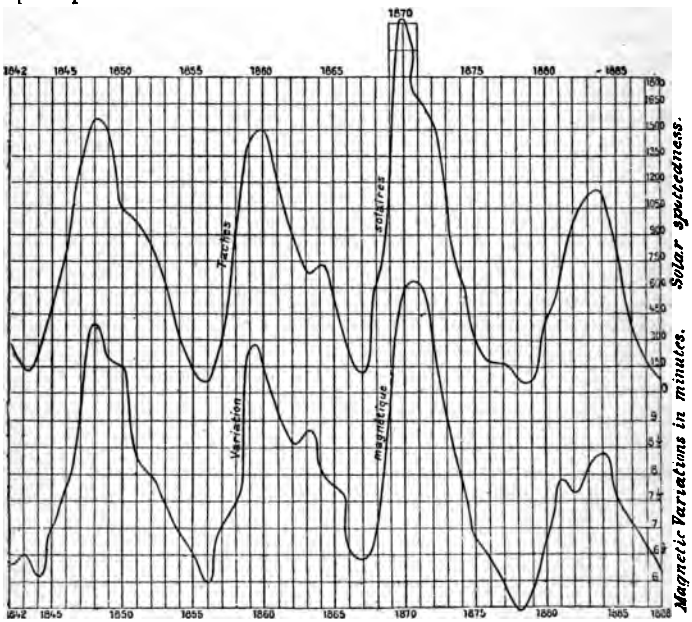

FIG. 80.—Correspondence between the amount of Solar Spots and the mean daily Magnetic Variation.

sun-spots on storms and rainfall. Thus Mr. Meldrum has given figures to prove that in the Indian Ocean cyclones are most frequent when sun-spots are most extensive; and that the rainfall at Madras and other stations is also greatest at such a time. At other places, however, this connection is not clear, so that, on the whole, the influence of sun-spots on the weather is still doubtful. Indeed, it is still uncertain whether the temperature is higher or lower at a period of sun-spot maximum; for although spots are cooler than the other parts of the photosphere, the diminished radiation from the spots may be compensated by increased radiation from the bright *faculæ* that so closely follow them.

84. **The Chromosphere.**—Passing now to the region beyond the sun's bright surface we find a gaseous envelope, lying immediately above the photosphere, which is usually known as the chromosphere (Gr. *chroma*, colour). It is so called because, when seen for a very short time during a total solar eclipse, it appears as a border of scarlet or rose-tinted light, the colour being due to the glowing hydrogen which the spectroscope shows to be its main constituent. In ordinary daylight, however, this less dense and rather cooler stratum resting on the photosphere, though hot enough to shine brightly, is quite invisible in presence of the brighter surface beneath it. The depth of this envelope, compared with that of the sun's diameter, is but small, varying from 5,000 to 10,000 miles. It is not spherical, for its boundary does not appear circular, but wavy or serrated. 'Its appearance has been compared very accurately to that of a prairie on fire; but the student must carefully guard against the idea that there is any real "burning" in the case; i.e. any *process of combination* between hydrogen and some other substance. The temperature is altogether too high for any formation of hydrogen compounds at the sun's surface.' —Young. The spectrum of the chromosphere is one of bright lines, proving that it consists of incandescent gases. The lines of hydrogen are most frequent and clear, but those of magnesium, sodium, and other metals have also been seen. (See Coloured Plate No. 10.)

85. **The Prominences.**—Besides the chromospheric envelope there are seen, during a total eclipse, fiery-red cloud-like protuberances of various forms, passing from the chromosphere. They are of various forms, extend in some cases beyond the limb of the sun to a distance of more than 70,000 miles, and frequently undergo rapid changes of shape. That the prominences are true solar appendages and do not belong to the moon is conclusively proved by the photographs taken at various phases of totality. These photographs show that the moon passes over them, first revealing those on the eastern side of the sun, and then, as the moon advances to the east, covering those up, and revealing those on the western limb. In fig. 81 we have a view of part of the chromosphere with the prominences

springing out of it, as seen in August 1869, when Mercury was near the sun. The reader may put on the scarlet hue.

Professor Lockyer and M. Janssen independently discovered, in 1868, a method of observing the prominences in full daylight. The image of the sun formed by the object-glass of an astronomical telescope is allowed to fall so that the edge of this image is just off the slit of a spectroscope *s s'* (fig. 82). If there be a prominence springing from this part of the limb, we shall

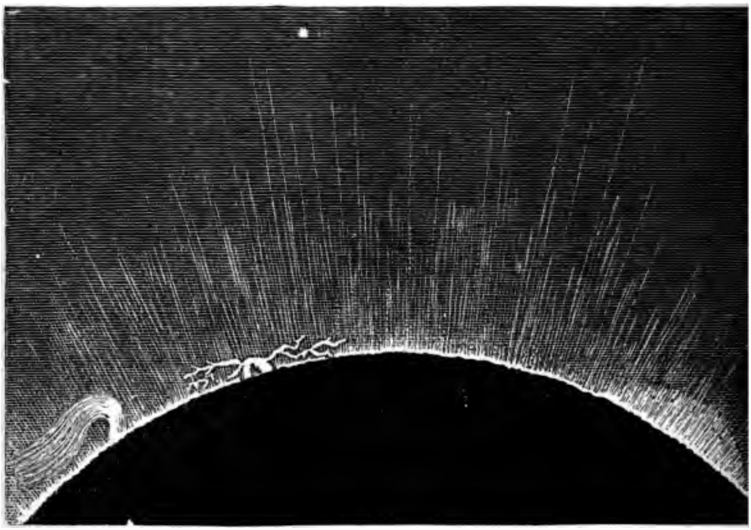

FIG. 81.—View of the Prominences seen during the Eclipse of August 1869.

obtain its spectrum, together with the continuous spectrum of the illuminated air. Now the spectrum of the prominence is the spectrum of a glowing vapour, and consists of a few bright lines, chiefly those of hydrogen, and in some cases those of magnesium, sodium, and iron, while the spectrum of the illuminated air is really the spectrum of ordinary sunlight, and is therefore continuous. By increasing the number of prisms in the spectroscope, the continuous spectrum may be so elongated and weakened in intensity as to be almost invisible,

while the same amount of dispersion produces on the spectrum of the prominence only an increase of space between the lines, with a little loss of brilliancy. Thus the characteristic lines of a prominence may be seen in full sunshine. Not only can the lines of a prominence be thus seen in sunshine, but by passing the slit of the spectroscope over the prominence, the varying height may be mapped down, and from this the form of the prominence may be obtained. Moreover, the general solar light being sufficiently reduced in brilliancy, allows of the slit being so far widened that the form of the prominence becomes visible when one of its spectrum lines is in the field of view.

Prominences have been divided into two chief classes (*a*) the quiet or cloud-like, and (*b*) the eruptive, metallic, or jet prominences. The first kind are found on all parts of the sun,

Fig. 82.

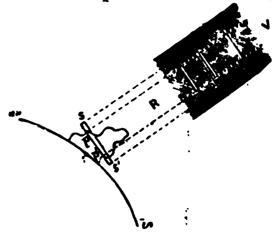

Fig. 83.

The Spectroscopic Analysis of a Solar Prominence.

and often appear like clouds in our own sky, or like plumes with a slender stem arising from the chromosphere. These often reach to enormous heights, and, though more enduring than the eruptive sort, are subject to rapid changes of shape. The spectroscope shows that these prominences consist chiefly of hydrogen and an unknown substance named 'helium.' The eruptive prominences are very different both in appearance and character. They exhibit the highest intensity of action, shooting up at times simultaneously to great heights, and with a velocity exceeding 100 miles per second. How this velocity is found will be explained presently. The tree-like prominence in fig. 84 was seen one day at half-past twelve o'clock, but was found half an hour later to have exploded into fragments, while the small mass at *a* grew into a surging flame. Secchi

says: 'It would seem that in the jet-prominences a part of the photosphere is lifted up (or broken through), whereas in the case of the plumes only the chromosphere is disturbed. The spectrum of the jet-prominences indicates the presence of several elements besides hydrogen.' It is interesting to inquire whether there is any periodic variation in prominence-activity similar to that observed in spot-activity. Such a variation has been found, and an analogous result appears to prevail regarding faculæ. The fluctuations of spots, eruptions, and faculæ are not entirely simultaneous, yet they appear to stand in some kind of inter-relation, and to mark the curious undecennial (eleven-yearly) fluctuation of solar energy already set forth. The metallic lines seen in the spectra of prominences appear with greatly changed intensities, and are not the same as the lines that are most widened in spots.

FIG. 84.- Prominences observed by Young.

FIG. 85.—Prominence observed by Young.

86. **Association of Solar Phenomena.**—Professor Lockyer, after constructing a diagram of curves summarising the results of Italian observations for the years 1881–1883, and after pointing out how closely the latitude of the maxima of spots, metallic prominences, and faculæ correspond, remarks : 'When and where the spots are at the maximum, the faculæ and the metallic prominences are at the maximum. If the maximum changes from north to south, as it does, in the spots, it changes from north to south in the metallic prominences, and from north to south in the faculæ. So that, were we dependent on these diagrams alone, representing three years' work, we should be driven to the conclusion that there is absolutely the most

intimate and important connection between spots, the metallic prominences, and the faculæ ; and not only that, we reach finally the fact of the wonderful localisation of these phenomena upon the sun. The spots are never seen north or south of 40°. They are invariably seen in smaller quantity at the equator. Similarly, while the domes are small all over the sun, the brighter collections of them, the faculæ, do not go very much farther than 40° north or south, and their minimum is also at the equator. The metallic prominences also never go very much beyond the spot region, and they also have a minimum at the equator.

'But when we pass to the prominences of the quiet sort, that is not so. They, like the domes, and the pores, and the veiled spots, extend from one pole of the sun to the other ; so that, whatever it may lead us to, we are bound to consider that there is an intimate connection between spots, metallic prominences, and faculæ, and that there is a great difference between the metallic prominences and the quiet ones.'

On this quotation we must, however, remark that some astronomers do not admit the association to be so close as that printed above, regarding spots and protuberances as two distinct manifestations of solar activity. Speaking of the solar prominences, Mr. Maunder says : 'Their records show that the variation in the number and size of the prominences does not proceed *pari passu* with that of the sun-spots, for though the period seems to be the same for both, the last maximum certainly fell later for prominences than for the spots. The prominences also do not correspond to the spots as to distribution in latitude, but rather to the faculæ.' The reader may judge for himself to some extent as to the amount of correspondence between spots and prominences by referring to the table in paragraph 82.

87. **The Corona.**—Besides the chromosphere and the prominences, there is seen during a total eclipse, round the moon's dark disc, a halo of light or 'crown of glory,' known as the corona. It consists of a bright inner light next the invisible sun, having a 'greenish pearly tinge' or a 'silver whiteness,' which melts into an outer, fainter, but more distinctly radiated,

light of much greater extent. This 'glory of radiant beams and bright streamers intersected by darker rifts' varies consider-

FIG. 86.—The Corona during the Eclipse of 1860 (*Feilitsch*).

ably in brightness and form at different eclipses. The inner brighter portion is nearly annular, but the outer radiated portion is sometimes more or less quadrangular, the streamers being

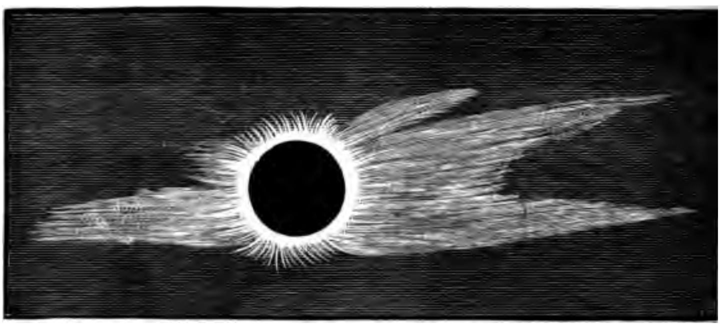

FIG. 87.—Drawing of the Solar Eclipse of January 1, 1889. Observed in California.

longest at the sun-spot zones. At the eclipses of 1867, 1878, *and 1889,* during epochs of sun-spot quiescence, the corona

was found to be less brilliant than at ordinary times, while a great extension, several times the diameter of the sun, was seen in the equatorial regions. Polar-streamers or plumes around the poles, and curving away in opposite directions, were also a well-known feature of these eclipses. This form of corona appears, therefore, to be characteristic of a minimum sun-spot period (see fig. 87).

The illumination of the earth's atmosphere prevents us from seeing the corona without an eclipsed sun, and we cannot place an artificial shadow outside our atmosphere. The moon does this for us during an eclipse, and thus keeps dark the part of the air through which the observer looks.

88. **Nature of the Corona.**—It was once held by some that the corona was an optical phenomenon of our own atmosphere, or that it was due to luminous matter surrounding the moon. Geometrical consideration and the evidence of photographs and the spectroscope have disproved these views. Photographs of the same eclipse taken at stations widely separated show such identity of detail as to prove that it cannot be due to the atmosphere of the observer. Bright lines in its spectrum prove that it contains a self-luminous gas, and no such gas is revealed near the moon, nor in our own atmosphere. It must, therefore, be an illuminated appendage surrounding the sun on all sides. Its light, which is usually twice that of the full moon, consists of three kinds, as is shown by the spectroscope: (1) light which gives a faint continuous spectrum and indicates the presence of particles of solid or liquid incandescent matter; (2) light which is resolved by the prism into bright lines, and indicates the presence of luminous gas probably surrounding the particles. The most conspicuous bright line in the spectrum of the corona is a green line at 1474 on the scale of Kirchhoff's map (λ5316). The origin of this line is unknown, no terrestrial substance giving it. The name *coronium* has been proposed for the substance producing it. Other bright lines are due to hydrogen. (3) Reflected sunlight scattered from the particles in which some observers have detected a few Fraunhofer lines. The matter of the corona must be in a state of extreme tenuity, for comets have been known to pass through it without any dis-

turbance of their motion being detected. Some of this matter is probably meteoric, though matter ejected from the sun and usually falling back upon it must also be concerned. The gaseous matter appears to suffer electrical repulsion similar to that acting on the matter raised from the head of a comet. The analysis of its light suggests, in the words of Professor Young, that the corona is a true solar appendage, 'an intensely hot but excessively attenuated cloud of mingled gas and fog and dust surrounding the sun, formed and shaped by solar forces.'

89. **Further Spectroscopic Examination of the Sun.**—We have explained, in a previous chapter, the principles of spectrum analysis, and have shown how the spectra of various terrestrial substances, when compared with the solar spectrum, prove the presence of these substances somewhere in the sun's atmosphere. The mode of proof consisted in establishing the remarkable accordance in position between the bright lines furnished by the glowing vapours of terrestrial elements and the dark lines of the solar spectrum. This solar spectrum was produced by submitting sunlight as a whole—that is, sunlight from any portion of its surface—to the dispersive action of a prism. A list of the elements thus identified as present in the sun is given in par. 70. But there remain several other points connected with the solar spectrum which we must now consider. In what parts of the sun's atmosphere do these elements exist? In other words, where does the absorption of certain rays of the white light from the photospheric clouds—the reversal of those bright rays which give rise to the Fraunhofer lines, take place? It must, as already explained, be in some part or parts of the sun's atmosphere, where there are the vapours of these elements glowing; but at a lower temperature than that of the white-hot solid or liquid particles giving the white light. According to some, these relatively cooler absorbing vapours form a stratum of about 600 miles in thickness close to the photosphere. In this stratum of mixed vapour called the 'reversing layer' the missing rays are assumed to be arrested because the spectrum of this envelope, when obtained apart from that of the sun's bright disc during a total eclipse, gives ***bright*** lines *corresponding* to the ***dark*** lines produced by its absorption

when there is no eclipse. But Mr. Lockyer doubts the existence of this shallow 'reversing layer,' and reports observations made during the total eclipse of 1882, of long faint lines in the higher regions of the sun's atmosphere. This would show that the Fraunhofer lines of the ordinary solar spectrum are produced by the combined absorption of all parts of the sun's atmosphere, and in Mr. Lockyer's view this atmosphere is very extensive and is composed of 'true strata,' each being at a higher temperature and of simpler composition than the one above.

We have hitherto spoken chiefly of the accordances between so many lines of terrestrial spectra and the dark lines of the solar spectrum, but we must remember that only about one-tenth of the solar lines have yet been identified. Further, most terrestrial elements that have been found to give evidence of their existence in the sun furnish spectra containing some lines not found in the solar spectrum, or some that differ materially in relative intensity. Now, we know that the spectra of most elements show considerable differences under varying conditions of temperature and pressure in the laboratory (par. 68). Hence the grave discordances and the number of unmatched lines in the solar spectrum indicate differences between solar conditions and the conditions under which the elements can be experimented upon in the laboratory. So that, when we say that hydrogen or calcium exists in the sun, we do not necessarily mean that it exists, as we know it, on the earth. It may be that the differences are only due to the different molecular grouping, and the different states of vibration of the atoms forming the substance, when subjected to the temperature of the laboratory, and when subject to the fierce heat of the sun. But Mr. Lockyer maintains that the discrepancies between solar and terrestrial spectra can only be explained by supposing that the substances we call 'elements' are decomposed or *dissociated*, and that 'if the terrestrial elements exist at all in the sun's atmosphere, they are in process of ultimate formation in the cooler parts of it.' This 'dissociation hypothesis' is also made to account for the absence of the non-metals, nitrogen, chlorine, &c., from the lists of elements present in the sun; for the

intense solar heat is supposed to separate them into simpler constituents, whose spectra we do not recognise. But here again it may be said, the apparent absence of these elements may possibly be explained by the hypothesis that the molecular states of these elements in the sun may be other than those with which we are acquainted, and therefore may produce spectra, even without dissociation, that are unknown to us.

90. **Spot Spectra.**—A sun-spot is only dark as contrasted with the bright surface of the sun's general disc, and it has been proved that even the blackest part gives out more light, surface for surface, than the full moon. Hence it produces a spectrum much fainter than that of the general surface. But this is not the only difference. Some of the lines appear much thicker or wider than usual, and also much darker, thus in-

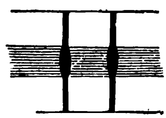

FIG. 88.—Thickening of the D-lines in the Spectrum of a Spot.

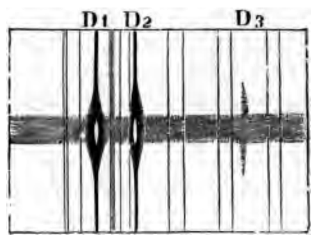

FIG. 89. - Reversal of the D-lines in a Spot.

dicating that the gases are cooler or denser than usual, and that there is greater absorption (fig. 88). At times, however, some of the dark lines disappear, or even become bright, either change indicating a great increase of temperature (fig. 89). New lines also frequently make their appearance in a spot-spectrum. But, more curious still, only a few of the lines of a chemical element out of those visible are widened in a sun-spot, and the most widened lines change with the sun-spot period. 'At, and slightly after, the minimum, the lines are chiefly known lines of the various metals. At, and slightly after, the maximum, the lines are chiefly of unknown origin.' This curious behaviour is used by Mr. Lockyer to support his theory of dissociation in his work on 'The Chemistry of the Sun.' The accompanying *illustration* will help the reader to understand the ordinary

sun-spot spectrum as far as it can be illustrated without the prismatic colours. The dark stripe is the spot-spectrum and shows clearly the increase in width of the lines and the appearances of additional dark ones. In the lowest part is the spectrum of a bright bridge, and the C and F lines of hydrogen are intended to be indicated in it as bright by the faint double lines. Finally, the thickened lines of a spot-spectrum, especially the F line of hydrogen, become somewhat displaced and are often broken, bent, and fringed in a singular fashion.[1] This displacement and distortion of lines is indicative of motion in the gas streams of the sun, as we will now explain.

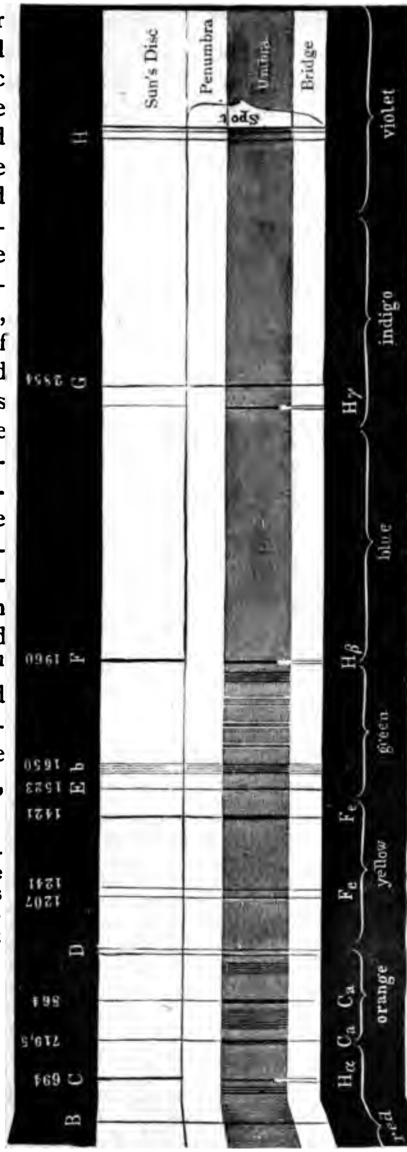

FIG. 90.—Spectrum of the Solar Spot of April 11 to 13, 1869, as observed by Secchi.

[1] On this subject Professor Young observes: 'In the motion-distortions of lines Lockyer finds strong confirmation of his ideas. It not unfrequently happens that in the neighbourhood of a spot, certain of the lines which we recognise as belonging to the spectrum of iron give evidence of violent motion, while close to them, other lines, equally characteristic

91. **How the Spectroscope indicates Motions of Approach and Recession.**—By the application of a principle first suggested by Doppler in 1842, it has been found possible on accurately measuring the displacement of the spectrum lines of a source of light, to determine whether this source of light is approaching or receding, and at what rate it is moving. The principle is that when a body emitting regular vibrations is coming rapidly towards us, then the number of waves received by us in a second is increased, and consequently their wave-length is diminished. An opposite effect is produced when the vibrating body is rapidly receding. This has often been illustrated in the case of sound. The whistle of a railway engine in rapid motion towards an observer causes the tone to rise in pitch, owing to the increased number of air-vibrations that fall upon the ear in a second, while the pitch falls as the engine mo away although the note sounded may have remained the sa 'As the various tones of sound depend on the rapidity of the vibrations, so the varieties of colour are regulated by the nu of ether-vibrations. If, therefore, a luminous object, as, instance, the glowing hydrogen of a prominence, be *rece* rapidly from us, fewer waves of ether will strike the optic ne in a second than if it were stationary.' On observing a placement, then, in one of the hydrogen lines of the so spectrum, say $H\beta$ $\lambda 4860$ situated at F in the greenish-blue, when the neighbouring dark lines suffer no displacement, we can safely refer the cause of this movement to that of the luminous hydrogen gas; for it cannot be due to the motion of the earth or the sun in these circumstances. As Schellen says: 'If the hydrogen in the sun were rapidly *approaching* us, the

of the laboratory spectrum of iron, show no disturbance at all. If we admit that what we call the spectrum of iron is really formed in our experiments by the superposition of two or more spectra belonging to its constituents, and that on the sun these constituents are for the most part restricted to different regions of widely varying pressure, temperature, and elevation, it becomes easy to see how one set of lines may be affected without the other. The same facts are, of course, also explicable on the supposition that there are several allotropic forms of iron-vapour, mixed together in terrestrial experiments but separated on the sun, and sorted out, so to speak, by the conditions of temperature and pressure.' Professor Lockyer's hypothesis appears to have as good foundation as that referred to in the last sentence of this *quotation.*

number of its ether waves in a second must increase; the length of each wave will become shorter and the light be inclined towards the violet. *The F-line suffers then a displacement from its usual position in the solar spectrum towards the violet end of the spectrum.* If the shortening of the ether-waves of this hydrogen line (Hβ) be only $\frac{1}{1000000000}$ of a millimètre, the consequent displacement of the F-line can be perceived, and the motion of the hydrogen on the sun be thus demonstrated.'

If, on the contrary, this gas be moving in the opposite direction, and be receding from us, the number of its ether-waves in a second will decrease, the wave-lengths will be augmented, the greenish-blue rays will approach the red, and

FIG. 91.—Contortions of the Hydrogen Lines in a Prominence, indicating movement of a Gas Vortex in the Sun.

a displacement of the F-line will be produced towards the red end of the spectrum. Fig. 91 shows displacements of the F-line of hydrogen in the chromospheric prominences where it is bright, the change beginning close to the sun's disc. The bright lines diverging from the normal position of the F-line (divergence in both directions is evident) indicate, by their displacement towards the violet end of the spectrum, that those portions of the prominences were in motion *towards* the earth, the greatest velocity indicated being 147 miles a second at least. Fig. 92 is only a small part of the solar spectrum, and shows the changes observed in the F-line of a solar spot. Some of the horizontal lines are caused by particles of dust on the

jaws of the slit, but the bands indicate the general absorption in the spot. Where the F-line is bright the hydrogen was hotter than the solar surface, but the bend towards the red end indicates that in the corresponding part the relatively cool hydrogen was moving from the eye in a downrush whose velocity exceeded fifty miles a second.

The spectroscope has not only been able to detect and measure the motion of gas-streams in the sun, but it has also been used to prove the fact of the sun's rotation. If the sun

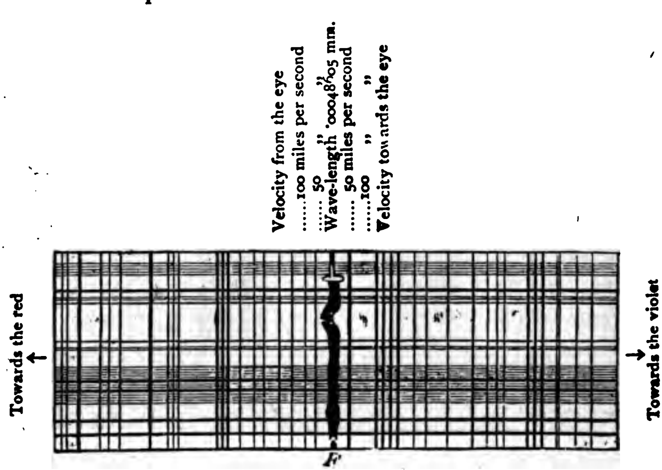

FIG. 92.—Illustrating the changes in certain Lines in the Spectra of Sun-spots.

rotates, as previously stated, in about 25·3 days, its eastern edge must be advancing at a rate of about $1\frac{1}{4}$ miles a second, and the western edge retreating at the same rate. According, therefore, to Doppler's principle, we ought, with a sufficiently powerful and accurate instrument, to find a general shift in the position of the lines of the solar spectrum towards the violet when the light is taken from the eastern limb, and towards the red when taken from the western limb. Such displacements of the solar lines have been observed, thus confirming the fact of rotation as derived from the observation of solar spots. Moreover, the spectroscopic examination of the two opposite limbs has

enabled us to distinguish the true solar lines from the telluric; for, as these latter are due to the atmosphere, they undergo no shift of position.

92. **Light of the Sun.**—Various estimates have been made of the sun's light and heat, but it will be readily understood that the figures given are not so reliable as those referring to its distance, size, and mass. By comparing the light of the sun when in the zenith with that of a standard candle at a distance of one yard it has been found that the sun illuminates a white surface 60,000 times more strongly than the candle does. Allowing for atmospheric absorption to the extent of one-seventh only, this number would become 70,000. If we then multiply this by the number of yards in the sun's distance, we get an estimate of the *quantity of sunlight* in 'candle power.' The result is about 1,575 billions of billions, or 1,575 followed by twenty-four ciphers. An estimate of the *sun's luminosity*—that is, the amount of light on each unit of luminous surface—shows, according to Professor Young, that the sun's surface is about 90,000 times as bright as that of a candle flame, and 150 times as bright as the limelight. A sun-spot is only relatively dark, for the darkest part is still brighter than the limelight. On throwing a large image of the sun on a screen, it is seen that there is a great diminution of light all round the edge, as the light from the limb has to pass on its way to us through a greater portion of the sun's atmosphere than the light from near the centre of the disc. According to Professor Pickering the light at the edge is only about one-third that at the centre. As a greater proportion of the blue and violet rays are absorbed in the sun's atmosphere than of the red and yellow rays, the light from the edge is of a brownish-red hue. This is clearly seen on throwing a large image of the sun on a screen in a darkened room, the darkness and ruddiness of the edge compared with the central parts being quite plain. In photographs of the sun, the absorption of light near the edge of the disc, and the more effective absorption from this light of the blue and violet rays chiefly active in ordinary photography, cause a striking difference between the appearance of the limb and the parts nearer the middle.

93. **Heat of the Sun.**—The quantity of heat received at the earth's surface when the sun is shining in a clear sky has been estimated by means of Pouillet's *pyroheliometer*. This is an instrument by which a circular beam of sunlight is allowed to shine perpendicularly upon a shallow cylindrical box of known area, containing a certain weight of water, for a given time. The rise in temperature is then ascertained, and knowing the specific heat of water, the quantity of heat received by each square unit of area of the earth's surface in a minute can be ascertained. Allowance must be made for the heat lost by reflection and for that absorbed by the atmosphere. The atmospheric absorption amounts to thirty per cent. of the whole when the sun is vertical, and to more than sixty per cent. when the sun is near the horizon. Expressed in *calories* (a calorie[1] being the amount of heat required to raise the temperature of one kilogram of water one degree centigrade) the amount of heat received by each square mètre of the earth's surface exposed perpendicularly to the sun's rays would amount in a minute to twenty-five, if there were no absorption in the atmosphere. This, according to Young, would melt yearly a layer of ice $136\frac{1}{2}$ feet thick if spread over the surface of the earth, supposing that the heat were equally distributed in all latitudes. Now the sun is a large globe of 433,000 miles radius, and sending out his energy into space in all directions. At a distance of 93,000,000 miles from his centre, the earth occupies a space represented by a circular area about 8,000 miles in diameter. From a consideration of these facts it can be shown that the amount of heat sent out from a square mètre of the sun's surface is 46,000 times greater than that received by a square mètre of the earth, and that somewhat less than the two-thousand-millionth part of the total radiation from the sun reaches our little world. We thus get 1,150,000 calories per square mètre per minute as the amount of radiation at the sun's surface, and this corresponds to a mechanical value of above 100,000 horse-power per square mètre in continuous action on the sun's surface. If we multiply 100,000 by $(6{\cdot}1 \times 10^{18})$, the number of square mètres in the sun's surface, we should get an array of figures representing the dynamical value in horse-power of the total solar radiation. This stupendous amount of working power is acting continuously, and we cannot but feel provoked to inquire how the development of the enormous quantity of heat which it represents is maintained.

94. **Maintenance of Solar Heat.**—That the sun is not a great fire or mass of burning fuel in which the heat is kept up by combustion is quite certain. Such a burning mass would diminish in size with a rapidity which would have made itself evident long ago. History shows us that there has been no great change in the intensity and light of the sun for the past three thousand years, and geology supplies proofs of the existence of life on the earth, and therefore of sunlight also, for one or more millions of years. No burning mass could have lasted such a time. That the sun is not a globe of incandescent matter, sending out light and heat into space without any further development within it, is also certain. Such a cooling globe would have shown a very perceptible fall of temperature within historic time, and there is no reason to think such a fall has occurred. Hence the sun must be an incandescent globe on which, or within which, an expenditure of energy occurs in a form to keep up the solar radiation without

[1] A calorie = 2·2 thermal units, a thermal unit being amount of heat required to raise one pound of water 1° C.

any sensible diminution of its size. Mayer ascribed the solar heat to the energy produced by the collision of meteoric bodies falling into the sun. A small portion of the sun's heat is probably obtained in this way, but the vast mass of meteors in the neighbourhood of the sun which this theory would imply, would have produced disturbances in the paths of the inferior planets, or in those of certain comets, which could not have failed to be detected. Helmholtz, the celebrated German physicist, has propounded a theory to account for the supply of solar heat which is now generally accepted. According to him the heat required to maintain the sun's radiation is almost altogether due to gravitative attraction in the sun's mass, the work done in slowly contracting upon itself under the influence of this force being sufficient to account for the enormous amount of the sun's radiation. In a mass as large as the sun, where gravitation is more than twenty-seven times terrestrial gravity, the heat developed, as the mass shrinks towards a central point, is enormous. Two opposing forces are thus at work in the sun's mass, the compressing force of gravitation and the expansive force of heat. Heat is continually passing off by radiation; an almost equal amount is restored by contraction due to gravitation. Under this process of shrinking the sun must become smaller and denser. As, however, a contraction of the sun's mass such as would reduce his diameter by the ten-thousandth part, would generate heat enough to cover the annual output during the last 2,000 years, no change has yet been perceived. But, accepting Helmholtz's theory, it follows that the sun's size must once have been much greater than now, that at some distant time in the future it will be much less, and that the sun's heat must have had a beginning, and will have an end.

95. **Origin and Age of the Sun.**—According to Helmholtz, the heat of the sun was produced originally by the condensation of a nebulous mass of matter once diffused in cosmical space. 'The particles of this mass falling together under the influence of gravity, the resultant motion being destroyed by friction and impact with the production of heat, the new world produced by such condensation must have acquired a store of heat not only of considerable, but even of colossal, magnitude.' Speaking of Helmholtz's theory, Sir William Thomson, in a lecture at the Royal Institution, thus described it: 'At some period of time, long past, the sun's initial heat was generated by the collision of pieces of matter gravitationally attracted together from distant space to build up his present mass; and shrinkage due to cooling gives, through the work done by the mutual gravitation of all parts of the shrinking mass, the vast heat-storage capacity in virtue of which the cooling has been, and continues to be, so slow.'

After an account of solar radiation and accepting Langley's measurement of its amount with an instrument called the *bolometer*, which allowed him to examine the radiation of the different parts of the spectrum separately, Sir William Thomson continues: 'In the circumstances, and taking fully into account all possibilities of greater density in the sun's interior, and of greater or less activity of radiation in past ages, it would, I think, be exceedingly rash to assume as probable anything more than twenty million years of the sun's light in the past history of the earth, or to reckon on more than five or six million years of sunlight for time to come.' Many geologists and biologists demur to this limitation of the sun's past activity, and demand more than twenty millions of years since life began on the earth; and, of course, millions of years must have preceded this time before the earth was available for plant and animal life. They found their claim

on the rate at which the various geological formations may be suppos
have been formed, and on the time required, according to the doctri
evolution, for the variation and modification of organic forms. The ra
energy of the sun cannot, according to this view, have been derived
gravitational energy alone, but the primitive nebulous mass must have
sessed a huge store to begin with. Such a store, according to Dr. C
might have been derived from the collision of two large cool bodies mee
together with enormous velocities. This 'impact theory' of the o
of the sun's heat is set forth in Dr. Croll's work on 'Stellar Evolution.

CHAPTER VI.

DESCRIPTION OF THE PLANETS.

96. BESIDES their apparent diurnal motion from east to w
caused by the revolution of the earth upon its axis, the bo
known as planets are revolving round the sun in an oppo
direction among the stars. This eastward motion of
planets, as seen from the sun, would appear as a nearly unif
motion in a circular orbit; but the earth is itself a pla
moving round the sun in a plane (the plane of the eclip
somewhat inclined to the plane of the planets' paths. T
motion of a planet, therefore, as seen from the earth, is
same 'as if the body had, combined with its own moti
another motion, identical with that of the earth, but revers
By carefully marking down, night after night, the position o
conspicuous planet on a celestial sphere or map, it will
noticed that the body, after advancing for some time from w
to east, gradually diminishes its speed, then stops, and beg
to move in the opposite direction. After retrograding for so
time, it again stops, and recommences its direct motion. T
time and the number of degrees passed over during this ret
gression are always less than during the eastward or dir
motion, so that there is on the whole an advance from west
east. The combined effect of the motion of the planets a
the earth's motion in the plane of the ecliptic gives rise, the
fore, to direct and retrograde movements in looped paths
various forms. 'Generally speaking, and comparing their pla
at distant times, they all advance, though with very differ

average or *mean* velocities, in the same direction as the sun and moon, i.e. in opposition to the apparent diurnal motion, or from west to east; all of them make the entire tour of the heavens though under very different circumstances: and all of them, with the exception of certain among the telescopic planets, are confined in their visible paths within very narrow limits on either side the ecliptic, and perform their movements within that zone of the heavens we have called the Zodiac.'

Fig.

In fig. 93 E C represents a portion of the ecliptic, and P Q R N S a portion of a planet's path. From P to Q the motion is direct, at Q the planet is stationary, from Q to R the motion is retrograde, and from R to S the motion is direct. Where the planet crosses the ecliptic, at N, it is said to be in its node.

97. **Positions of the Planets.**—By the help of fig. 94 we can illustrate the meaning of some terms in frequent use. E represents the position of the earth at a certain point of its orbit. The inner circle represents the orbit of an inferior planet like Venus, and the outer circle stands for the orbit of a superior planet. The angle formed by the two lines drawn from the earth to the sun, and to a planet, is called the *elongation* of the planet from the sun. The elongation is east or west according as the planet is on the east or west side of the sun. The angle P E S is the elongation of the superior planet P at that particular position of its orbit. Moving further in its orbit its elongation increases, and it is said to be in *quadrature* when it is distant from the sun 90° in longitude. When its longitude differs from that of the sun 180°, the planet is said to be in *opposition* with the sun, the planet being on the side of the earth *opposite* to the sun. When a planet and the sun are on the same side of the earth—that is, when they have the same longitude—the planet is said to be in *conjunction* with the sun, and it is evident from the figure that an inferior planet has two conjunctions—an *inferior conjunction* when nearest the earth, and a *superior conjunction* when most distant. If at the

time of inferior conjunction the inferior planet Venus should happen to be at one of its nodes and therefore in the plane of the ecliptic, it would be seen to pass across the face of the sun as a dark spot. Such a phenomenon, called a *transit* of Venus, rarely happens, as the passage through the node seldom occurs at the time Venus is between the earth and the sun. It will be readily understood from the figure that the angle representing a planet's elongation may have, in the case of a superior planet, any value from 0° to 180°, but for an inferior planet there is a

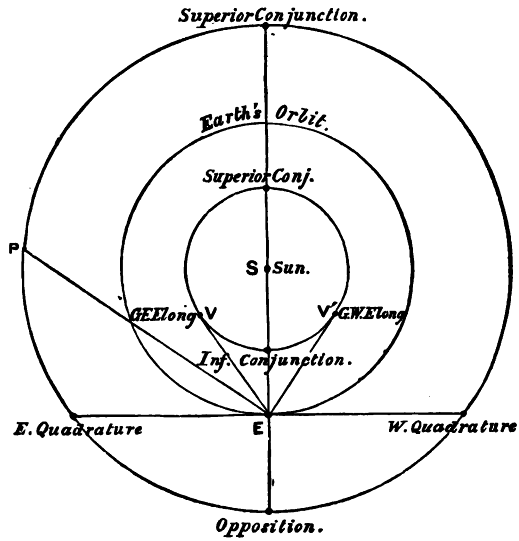

FIG. 94.—Planetary Configurations and Aspects. (After Young.)

maximum value depending on the size of the orbit. Thus the angle V E S or V′ E S in the case of Venus cannot exceed 47°. Hence, an inferior planet, in revolving about the sun, appears to us to pass backwards and forwards from one side of the sun to the other, never getting far away, and being, therefore, visible a little while after sunset, or before sunrise, according as it is east or west of the sun. When a planet is in conjunction with the sun, it will pass the meridian with the sun at noon and is *therefore* above the horizon only during the day. When a

planet is in opposition with the sun, it will pass the meridian about midnight, and when in quadrature at about 6 o'clock morning or evening.

98. **Periods.**—The *sidereal* period of a planet is the time required for one complete revolution round the sun, i.e. the time *as seen from the sun* in which it passes from a star to the same star again. The *synodical* period is the interval between two successive conjunctions of the same kind, or two successive oppositions. The sidereal periods of the planets may be obtained by observing their passages through the nodes of their orbits, allowance being made for a slight shift in the position of the line of nodes.

99. **Mercury.**—From the tables given in Chapter II. it will be seen that Mercury is the nearest major planet to the sun, that it moves most quickly in its orbit, and that this orbit is the most eccentric and has the greatest inclination to the ecliptic. It has also the least diameter, the least mass, and the greatest density of all the planets. Its mass and density have not been conclusively determined, though there is little doubt that its density exceeds that of the earth. Its proximity to the sun makes it a difficult object for observers, its greatest possible elongation never exceeding 27° 45′. It may sometimes be seen with the naked eye for a short time after sunset in spring (E. elongation), and before sunrise in autumn (W. elongation).

The equator of Mercury appears to have an inclination of about 20° to the plane of its orbit, and its rotation-period has quite recently been found by Schiaparelli to be the same as its period of revolution round the sun.[1] It will, therefore, behave to the sun as the moon does to the earth; one half will be always exposed to the intense light and heat of the sun, and the other half will be in continual darkness. The great eccentricity of its orbit, however, produces considerable libration, and causes its actual distance from the sun to vary from $28\frac{1}{2}$ millions of miles at perihelion to $43\frac{1}{2}$ millions of miles at aphelion, so that the heat received at these two periods of the sun will be in ratio of 9 to 4.

Viewed through a telescope the planet looks like a little moon, and shows phases similar to those of our satellite. At inferior conjunction its dark side is turned towards us, and at superior conjunction, when it is most distant, we see the whole of the illuminated half and it appears full. At its greatest elongations it appears as a half-moon. Between superior con-

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[1] The rotation-period of a planet, or the length of the planet's day, is found by observing some marking on the disc, and noting the time between its returns to the same apparent positions. Allowance must be made for the change of position of the planet relative to the earth.

junction and the greatest elongations we see more than half the illuminated surface, so that it is gibbous, while between inferior conjunction and the greatest elongatións, we see less than half the illuminated surface and it has a crescent appearance. These varying phases and the variations in the apparent size due to change of distance from the earth, are somewhat similar to those shown for Venus in fig. 96. The telescope teaches but little regarding the planet's surface, for hardly any well-defined markings can be seen from which to deduce the planet's rotation-period. When in the crescent phase the horns or cusps sometimes appear blunted. The existence of an atmosphere is doubtful. 'It seems certain that Mercury does not at present possess both air and oceans, for, if he did, great quantities of vapour would be raised from the waters and condensed over wide tracts into clouds. These clouds would reflect a large proportion of the light falling on them; and thus the average whiteness of the planet would be raised much above that of the moon, instead of being far below.'—Proctor.

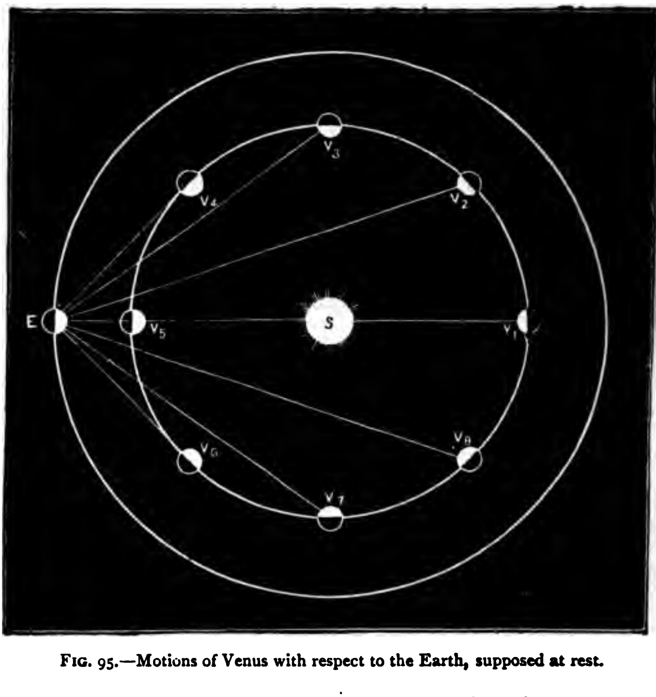


FIG. 95.—Motions of Venus with respect to the Earth, supposed at rest.

100. **Venus.**—Venus is the second planet in order of distance from the sun, its mean distance (67,000,000 miles) being about $\frac{723}{1000}$ that of the earth. The eccentricity of its orbit is very

small (·007), and consequently the difference between the greatest and least distances from the sun is only about 47,000 miles. In size it comes nearest to the earth, for its diameter may be taken at 7,700 miles, that of the earth being 7,918. Its *mass*, found by means of the perturbations it produces upon the earth, is $\frac{78}{100}$ that of the earth, from which a *density* of 86 per cent. that of the earth may be deduced. The inclination of Venus's axis to the plane of its orbit has not been satisfactorily determined, but its rotation-period is believed to be 23 h. 21 m.[1] As it is the planet moving in the orbit nearest to that of the earth, its distance from us varies greatly. At inferior conjunction it is only at a distance of 26 millions of miles (93—67), but at superior conjunction it is 160 millions of miles away (93+67). By means of fig. 95 the motion of this planet with

FIG. 96.—Phases of Venus.

respect to that of the earth and the different phases which it presents will be readily understood, less and less of its illuminated surface being visible as it gets nearer the earth.

At V_1 it is in superior conjunction and would appear as a full disc, at V_2 it would appear gibbous, at V_3 it is still gibbous, at V_4 (greatest easterly elongation) it appears like half a moon, at V_5 (inferior conjunction) it is invisible, being lost in the sun's light, unless, indeed, it happens to be in or very near the plane of the ecliptic, when it would be seen to *transit* the face of the sun as a black spot. As it approaches the earth, its apparent diameter increases in size, the variation ranging from 11″ to 67″.

Venus makes a complete revolution in its orbit in 224·7 days, and this gives its *sidereal period*; but if we suppose the Earth and Venus to start

[1] Since the above was written, Schiaparelli has found that Venus, like the moon and Mercury, rotates on its axis in the same time that it takes to make a sidereal revolution round the sun, and that the axis of rotation is nearly perpendicular to the plane of its orbit.

together in their orbits from inferior conjunction with their respec orbital velocities it will be 584 days before Venus is again in inferior c junction, which gives its *synodic period*. About five weeks before after inferior conjunction Venus appears brightest, and can then be seer full daylight by the naked eye. Its *albedo*, or reflecting power, is ab three times that of the moon, and this high reflecting power probably dicates that its surface is wrapped in layers of cloud. That Venus an atmosphere appears certain; for near inferior conjunction a curved l of light is often to be seen as a continuation of the narrow crescent of planet itself, and at a time of transit a ring of light appears as the pla enters upon the sun's disc. These appearances can only be explained the refraction of sunlight in the planet's atmosphere. The observati

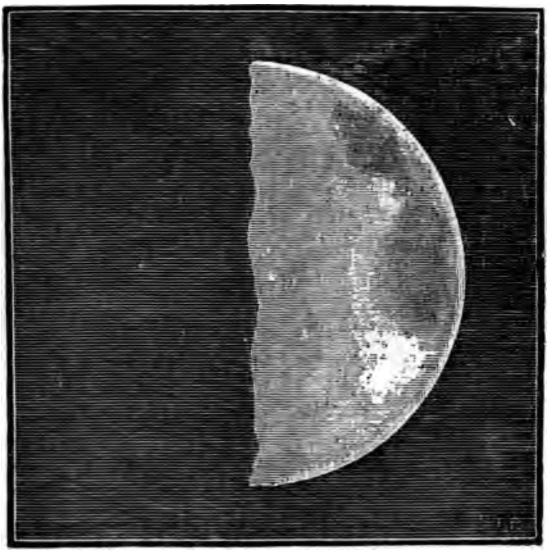


FIG. 97.—Venus when half-full. (*Folache.*)

on the refractive power of this atmosphere point to an atmosphere de than that of the earth, and the spectroscope furnishes evidence of presence of water-vapour in it. The telescopic appearance of Venus w half-full is shown in fig. 97.

101. **Mars.**—This planet is situated at a distance of 1 millions of miles from the sun, its *sidereal* period being days, and its *synodic* period 780 days. Its average dista from the earth at opposition is its mean distance from the *minus* the earth's mean distance, but if the opposition occ

near the planet's perihelion this is reduced to 35,500,000 miles, owing to the great eccentricity of its orbit. When in conjunction its average distance is $234\frac{1}{2}$ millions of miles ($141\frac{1}{2}+93$). Its diameter is about 4,200 miles; its mass about $\frac{1}{9}$ that of the earth, and its density a little more than $\frac{7}{10}$ that of the earth. Its superficial gravity is only 38 per cent. compared with the earth's, so that a body weighing 100 pounds here would only weigh 38 pounds on Mars. Both the time of its rotation, 24 h. 37 m. 22·67 s., and the inclination of its equator to the plane of its orbit, 24° 50′, are nearly the same as those of the earth. The determination of the exact value of its rotation-period has been rendered possible by the existence of distinct markings on its surface, some of which have been observed for over 200

FIG. 98.

FIG. 99.

The Planet Mars in 1877.

years. As the orbit of Mars is outside that of the earth, it never comes between us and the sun, and can never appear in the crescent form; but at quadrature, a small part of the illuminated surface being turned away from the earth, the planet then shows a gibbous phase. Seen in a telescope the disc of Mars has a ruddy appearance, but in a good instrument two varieties of tint are distinctly apparent—dark or dusky patches which represent seas and tracts, and lighter yellowish patches which represent land. These markings pass across the disc as the planet revolves, and therefore undergo changes dependent on the hemisphere turned towards the earth. But their permanence is shown by the continual reappearance of the same forms when the same side of the planet is presented to us. In many respects there is a curious resemblance between the

hysical relations existing on Mars, and those existing on th earth, yet the differences between the two must not be los sight of. 'There is no other major planet which probably i so little enveloped and obscured in atmospheric vapours. The definite outlines of his surface-markings become visible agair and again with the same relative distinctness, and preserve a perfect integrity of figure, so far as our knowledge extends. Hence the rotation-period has been computed with exceptional precision, and we may rely upon it that this period is not that shown by atmospheric currents, but by objects which form the physical delimitations of his real surface. In this respect Mars appears to be unique, for the other planets are all more or less involved in dense atmosphere, originating a series of variable phenomena visible in our telescopes; but their real surfaces are rarely if ever discerned, so that we are quite ignorant as to the material features underlying the outer vaporous envelopes.'[1]

So carefully have the features of Mars been ascertained that maps of his surface have been constructed and names assigned to the various parts of land and sea. But though the general geographical configurations are thus permanent, some of the outlines appear to some extent variable. It will be noticed that the proportion of land and water is about equal, that these two substances are strangely interlaced, and that snow appears round the poles. That these white caps round the poles are really snow or ice seems proved by the fact that the one around the pole turned towards the sun is greatly reduced in size, while in the winter season of each hemisphere the white circle reaches to latitude 45°. These polar ice-caps show that there must exist large bodies of water from which are raised the vapours whose condensation produces the snow. It should be mentioned that the Italian astronomer Schiaparelli has described a number of curious dark lines, having a general direction in latitude, as existing on the planet's surface. The 'canals' as they are called, when observed at the opposition of 1882 appeared double, exhibiting a remarkable parallelism. As to the cause and significance of these 'double canals' astronomers are still in ignorance. The existence of an atmosphere on Mars is proved by the fact that the markings are at times obscured by patches of white light, which are evidently the upper surfaces of cloud masses. This atmosphere is probably but thin, otherwise we could not so well discern the planet's surface, and the colour of the polar snow-caps remains unaffected by it, thus rendering it probable that the ruddy hue of the planet is due to the nature of the soil. Moreover, gravity there has less than half the force it has here, so that there would be much less condensation in the atmospheric covering. The light of the planet examined in the spectroscope shows

[1] W. F. Denning, in *Astronomy for Amateurs.*

that it is only reflected sunlight, with the addition of lines indicating the presence of aqueous vapour in its atmosphere.

Mars has been called a 'miniature earth' because its physical con

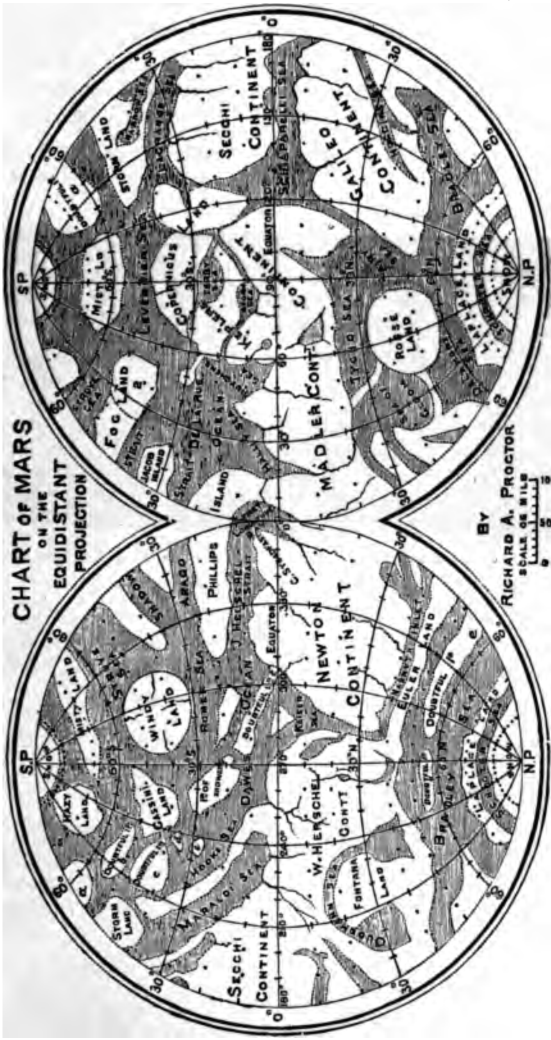


FIG. 102

dition appears to resemble the earth's more closely than that of any oth
planet. It has polar, temperate, and tropical regions; it has summer an
winter, land and water, and its atmospheric conditions generally see
closely analogous to those of the earth.

102. **Satellites of Mars.**—Until the year 1877 no satellites were known but in that year Professor Hall of Washington discovered two small bodi revolving round the planet. The inner one, named Phobos, is only 5,8c miles distant and has a period of 7 h. 39 m. (less time than that in whic the planet rotates), while the outer one is at a distance of 14,600 mile with a period of 30 h. 18 m. An estimate of their size deduced from the light-reflecting powers, shows that their diameters are probably somewhe between ten and twenty miles. Such small bodies can give but a sma fraction ($\frac{1}{14}$) of the light we derive from our moon.

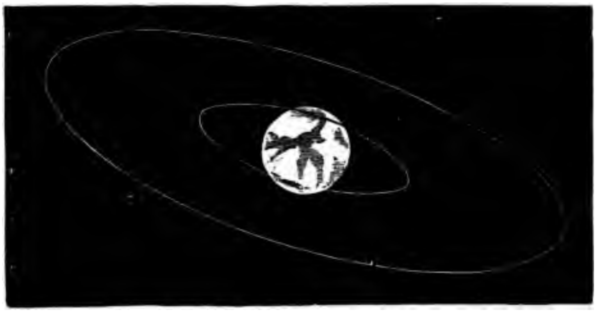


FIG. 101.—Orbits of the Martian moons, Deimos and Phobos, round the planet as situated in August 1877.

103. **The Minor Planets or Asteroids.**—Between the orbits of Ma and Jupiter there is a wide gap, in which, however, a group of small planet circulate round the sun. The first of these was discovered on the fir day of the present century, and at present nearly 300 are known. The are difficult to find, as they only shine like faint stars. Having a carefull prepared star-chart of a certain region of the sky near the ecliptic, th astronomer diligently watches this part of the sky night after night. I at any time he finds a point of light not on his chart, it is watched wit great attention. In the course of a few hours, it will move perceptibly it is a planet, its motion being detected by measuring with the micr meter its distance from a fixed star near. The minor planets are a named, and have a number indicating the order of their discovery. Th orbits of these small bodies are at very various distances from the sur Medusa (149) being the nearest and Hilda (153) the most distant. Th average inclination of the orbits is about 6°, but Pallas (3) has an incl nation of 35°. Several orbits are also very eccentric, that of Æthra (13 having the greatest eccentricity, 0·38. As to their size and mass but littl is known. Vesta, the brightest, is probably about 300 miles in diamete but the whole number known form only about $\frac{1}{4000}$ part of the earth's bull Several views are held as to their origin. Some believe that they are th *fragments of* a larger planet, destroyed either by collision or by explosions

others regard them as the material which ought to have collected into a single planet, but which has failed to do so from some unknown cause.

104. **Jupiter.**—In figure 102 (from Proctor) we have a representation of the paths of the Earth, Mars, and part of that of

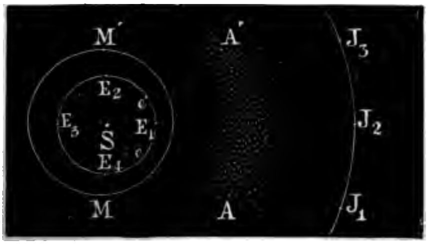


FIG. 102.

Jupiter, with a diagrammatic representation of a portion of the zone of asteroids. The orbital velocity of Jupiter is so much less than that of the earth, that if the earth start from *e* when Jupiter is in opposition at J_1, by the time the earth is at E_3 Jupiter has only reached J_2, where he is in conjunction. When the earth has again come back to *e*, Jupiter has only gone through about $\frac{1}{12}$ of his orbit, and by the time the earth is at *e'*, Jupiter has reached J_3, where the sun, the earth, and Jupiter are again in the same line. The *synodic* period of Jupiter is only 399 days, but its sidereal period is $11\frac{9}{10}$ years. Jupiter travels in an orbit round the sun at a mean distance of about 483 millions of miles. The eccentricity of its orbit is nearly $\frac{1}{20}$, so that there is a variation between the greatest and least distances from the sun of more than 42 millions of miles. Its diameter is nearly eleven times that of the earth, and its bulk 1,300 times that of the earth. Its density is about $\frac{1}{4}$ that of the earth ; from which we get a mass rather more than 300 times the earth's mass. Indeed, its mass is more than double that of all the other planets put together, and its bulk is about $1\frac{1}{2}$ times all the rest. It, therefore, well deserves the appellation of 'The Giant Planet.' The ellipticity of Jupiter is considerable, $\frac{1}{17}$, that of the earth being $\frac{1}{294}$. This produces a difference of more than 5,000 miles between the equatorial and polar diameters. The *albedo*, or

reflecting power of the planet's surface, is very high, 0·62, that of white paper being 0·78. Like the sun, and unlike the moon, Mars, Venus, and Mercury, the centre of its disc is brighter than the limb.

The time of rotation on its axis, as deduced from observations of the motions of spots on its surface, is only 9 h. 55 m. This is a more rapid axial rotation than that of any other planet. As its axis is only inclined 3° to that of its orbit, it can have no seasonal changes so far as inclination of axis is effective.

FIG. 103.—Jupiter, February 5, 1872. (*Lohse.*)

105. **Telescopic Features of Jupiter.**—In a good instrument the disc of Jupiter appears large, and shows many interesting variations. The most striking features are dark and light zones, called belts, lying more or less parallel to the planet's equator and possibly so disposed by the rapid rotation of the planet. These belts are probably shallow fissures in the dense atmosphere of the planet; for a dense atmosphere is needed to account for its great reflecting power. Though the belts are, in general arrangement, fairly permanent, yet they undergo minor variations which prove their atmospheric character. Occasionally, slanting belts are seen, and egg-shaped forms resembling shaded clouds. But the most remarkable feature is a great red spot in the southern hemisphere at the southern edge of the great equatorial belt, first noticed in 1877 (see fig. 104). In the following year this spot was of a clear brick-red colour, but since then it has undergone remarkable changes in brightness, while still retaining nearly the same form and size.

Like the belts it is attributed by many astronomers to a depression in the atmosphere of the planet, its red colour being derived from the actual

surface of the planet beneath, or from the redder vapours of the lower atmospheric strata. Oval white spots are also seen at times on the planet's surface, a brilliant one of this colour having been conspicuous tor the last few years on the equatorial border of the southern belt. This spot shows a greater velocity per hour than that of the red spot. Generally, indeed, the spots near the equator travel faster than those in higher latitudes, as is the case on the sun. Most astronomers believe that what we see is merely a shell of clouds, and not the real surface of the planet. How deep this atmosphere of clouds is, and what the real size and density of the inner kernel are, we have no means of determining with certainty. As the heat derived from the sun (about $\frac{1}{26}$ of that received by the earth) would neither be sufficient to raise the cloud masses seen on Jupiter nor to produce the rapid changes which these masses undergo, it has been maintained that the planet itself is still at a high temperature, even at its surface, not having cooled down so far as the planet on which we live. It thus represents an earlier stage in planetary life than the stage at which the earth has arrived. The spectrum of Jupiter shows that the light is mainly reflected sunlight, probably from the planet's varying envelope of clouds, for the Fraunhofer lines are quite distinct; but it differs from the solar spectrum in the presence of some dark bands, the most striking of which is a strong one in the red. Certain indications of inherent light have been described by some observers, but it is hardly probable that the planet can still be so hot as to be sensibly self-luminous.

FIG. 104.—Great oval Red Spot on Jupiter in 1877. (Inverted telescopic view.)

106. **Jupiter's Satellites.**—Jupiter possesses four satellites, first discovered by Galileo. The following table gives the chief figures connected with these bodies.

Satellite	Distance from Jupiter	Period			Diameter
	Miles	d.	h.	m.	Miles
I	260,000	1	18	29	2,400
II	414,000	3	13	18	2,100
III	660,000	7	4	0	3,400
IV	1,161,000	16	18	5	2,900

As the orbits of Jupiter's satellites lie almost in the plane of the planet's orbit, they all, except the fourth, pass through the shadow of the planet

and suffer eclipse at every revolution. The fourth satellite fails to be eclipsed when Jupiter is far from the node of the satellite's orbit. The time at which these eclipses occur undergoes a peculiar variation, first explained by the Danish astronomer Roemer. The earth moves through its whole orbit while Jupiter is moving over about one-twelfth of his. For the sake of simple explanation, let us suppose that in fig. 105, Jupiter occupies the position I, while the earth makes a revolution. When the earth is near E, *i.e.* at the time of opposition, the interval between two eclipses of a satellite is noted.

As the earth moves on its orbit, the distance between the earth and Jupiter becomes greater and the interval between two eclipses increases. On arriving at F the earth is further from Jupiter by twice its distance from the sun, or twice 93,000,000 miles. At F, *i.e.* at the time of conjunction, the eclipses occur very nearly 1,000 seconds later than when the earth was at E, the time of opposition. This must be the time required for the light to travel across the distance E F, or twice the distance of the earth from the sun. Knowing the distance of the earth from the sun we can ascertain the velocity of light by dividing this distance by the time light takes to pass over this space. This time is half that required in passing from E to F, viz. 500 seconds nearly. Now $\frac{93000000}{500}$ gives **186,000 miles** per second as the velocity of light as calculated from these eclipses. After

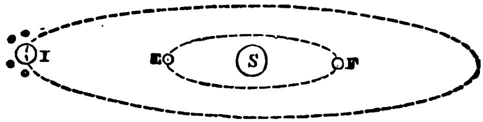


FIG. 105.

conjunction, as the earth moves on towards Jupiter, the eclipses take place in shorter intervals till the earth and the planet are again in opposition. The time required for light to traverse the distance between the earth and the sun is sometimes called 'the equation of light.' Knowing this time and the velocity of light as determined by the experiments of Fizeau and Foucault, we can reverse the above problem and deduce the distance of the sun. The question, then, becomes, If light passes over 186,000 miles in a second, what is the distance traversed in 500 seconds?

107. **Saturn.**—Passing from the fifth to the sixth primary planet we almost double our distance from the sun, for Saturn's mean distance is a little more than $9\frac{1}{2}$ times that of the earth, and Jupiter's is a little more than $5\frac{1}{2}$ times that of the earth. Its sidereal period is about $29\frac{1}{2}$ years, and its synodic period 378 days. The compression of its figure is greater than in any other planet, the ellipticity being $\frac{1}{9}$. The mean diameter is about 71,000 miles, the equatorial diameter exceeding the polar diameter by 7,000 miles. Hence its volume is 740 times *that of* the earth, though its mass only exceeds that of the

rth 95 times. From this it follows that its density is only out $\frac{1}{8}$ that of the earth, so that it is lighter than water. It volves on its axis in about 10 h. 15 m., the inclination of the is to the plane of its orbit being 28°. Like Jupiter it shows belted surface, but these atmospheric belts are not so clearly arked nor so variable as those of the giant planet. A bright ne extends some distance on each side of the equator, as own in the engraving. The spectrum of Saturn shows that the flected sunlight has suffered some absorption in the planet's mosphere, for there are some unexplained dark bands at the red ıd of the spectrum similar to those observed in the spectrum of

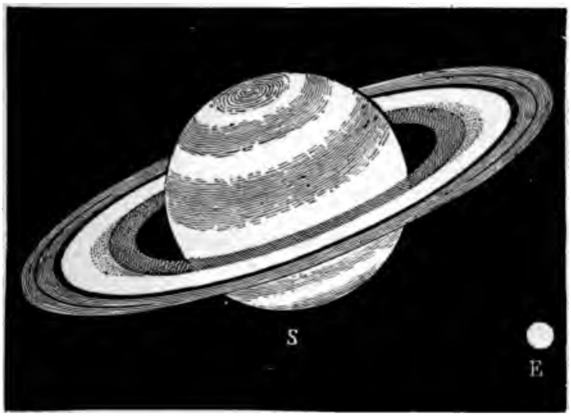


FIG. 106.—The Globes of Saturn, S, and the Earth, E, on the same scale.

ıpiter. But Saturn is unique among the planets, its cloud-lted globe having a retinue of eight satellites, and being sur-unded by three thin concentric rings made up of discrete odies. Its physical condition and constitution closely resemble ose of Jupiter, though the body of the planet is probably mewhat cooler.

108. **Rings of Saturn.**—The three rings of Saturn are three flat thin cular discs pierced in the middle and having a total breadth of about ,000 miles. The two outer ones are bright, while the third or 'crape' ıg, discovered in 1850, is but feebly luminous, and its inner edge is almost ,000 miles from the planet's disc. This inner dusky ring can be seen rough at times, and *must therefore* be thinner or composed of more

scattered materials than the outer ones. Between the two outermost rings there is also a space of about 1,600 miles, known as Cassini's division, while in the exterior ring a division, known as Encke's division, has been noted. The rings are doubtless circular, but we see them foreshortened, so that they appear more or less oval, or else, when we are nearly in the same plane, they appear like a straight line. Thus, while the rings remain parallel to the equator of the planet, which is inclined about 28° to the plane of the ecliptic and 27° to the plane of the planet's orbit, they present to us different phases, twice appearing edgewise and twice at a maximum opening in each revolution. The apparent breadth is at present very little, and in 1891 they will appear as a line, after which they will gradually open out, so as to present a good view in 1899. At times the distinction between the dark ring and the inner edge of the neighbouring bright ring is much more marked than at others, while divisions are occasionally seen in the dark ring for a short period only. Other unexplained changes have also been noticed in the rings. It requires a good instrument to see the rings when presented edgewise to the earth, and then a 'slight nebulosity' is sometimes observed on each side, as shown in fig. 107.

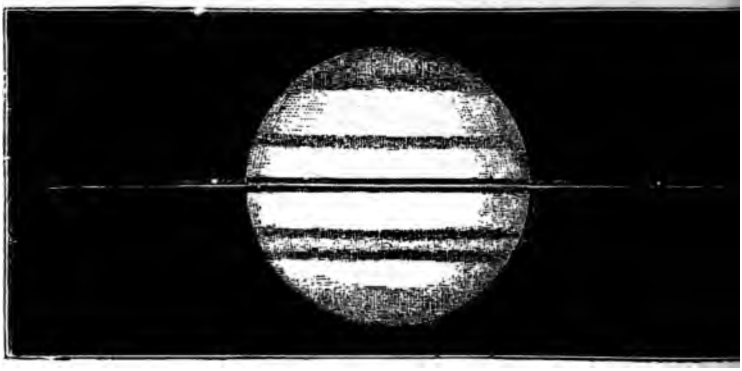


FIG. 107.—Rings turned edgewise, December 26, 1861. (*Wray.*)

The thickness of the rings is proved to be small, probably not more than 100 miles, by their appearance as a line every fifteen years when their plane is directed towards the earth. Mathematicians have shown that the rings cannot consist of continuous sheets of either solid or liquid matter, but that they are formed of a multitude of separate independent bodies revolving in circular orbits. They are, in fact, a multitude of small satellites, like swarms of meteorites, and there is nothing improbable in supposing continual collisions among such bodies, with the production of vaporous surroundings. The spectroscope has not, however, as yet, given any decisive evidence of glowing vapours in the ring system of Saturn.

109. **Satellites of Saturn.**—Eight satellites are known to revolve around Saturn, all of them being exterior to the ring system. Their names, distances from Saturn, and times of revolution round their primary, are set forth in the annexed table. All revolve in the same plane as the plane of the rings, except Iapetus, which is inclined to this plane about 10°.

Names of Satellite	Distance from Saturn	Period		
	Miles	d.	h.	m.
Mimas	121,000	0	22	37
Enceladus	155,000	1	8	53
Tethys	192,000	1	21	18
Dione	246,000	2	17	41
Rhea	344,000	4	12	25
Titan	797,000	15	22	41
Hyperion	1,008,000	21	7	7
Iapetus	2,317,000	79	7	57

Iapetus, the most distant, shows a remarkable variation in brightness, the western side being more than twice as bright as the eastern. This is explained by supposing that, like our moon, it continually keeps the same face towards the planet. Titan, the largest, has a diameter of about 32,000 miles. The orbit of Hyperion shows distinctly the disturbing effects produced by Titan, the largest of the satellites.

110. **Urănus.**—Urănus was discovered by Sir William Herschel in 1781, and its planetary character was established shortly after by Lexell. Its distance from the sun is more than 19 times that of the earth; its diameter is more than 4 times that of the earth, with a volume therefore more than 64 times that of the earth; its density is less than $\frac{1}{4}$ that of the earth; and its ellipticity amounts to about $\frac{1}{12}$, that of the earth being only $\frac{1}{293}$. Seen in a good telescope it shows a sea-green disc, with faint bands or belts, from which a rotation-period of 10 to 12 hours has been deduced. This rotation, however, appears to take place in a direction almost perpendicular to the plane of the planet's orbit. Its spectrum shows dark bands in the green, and the F line is clearly seen. Hence it has been thought to have a dense atmosphere. Uranus has four satellites, Ariel, Umbriel, Titania, and Oberon, revolving in orbits very nearly circular, and apparently in one plane; but the peculiarity of these orbits is remarkable, for the plane of the orbits of the satellites of Uranus is inclined 82° to the plane of the ecliptic, and in that plane the satellites revolve from east to west, or in a direction opposite to that of all the bodies in the solar system, except also the single known satellite of Neptune.

111. **Neptune.**—Neptune, the most distant planet, was discovered at Berlin in 1846. The history of this discovery furnishes a striking example of the marvellous results achieved by mathematical astronomy. The

motions of Uranus had for some time made evident the existence of a more distant planet, as the perturbing influence of such a body would alone account for the effects observed. Two distinguished mathematicians, Leverrier in France and Adams in England, therefore in 1844-5 entered upon a laborious investigation and calculated the approximate place of the unknown planet. While Professor Challis was employing the results of the calculation of Adams in searching for the missing planet, Dr. Galle, aided by a more recent star-map of that part of the heavens, found it close to the place indicated by Leverrier. Neptune's mean distance from the sun is nearly thirty times that of the earth; its density not quite $\frac{1}{4}$ that of the earth; and its mass 17 times that of the earth. At so great a distance no distinct markings on its surface can be discerned and hence the time of its axial rotation is unknown. The light and heat received from the sun, diminishing with the square of the distance, can only be $\frac{1}{900}$ part of what the earth receives, while the sun itself, seen from Neptune, would only appear as large as Venus when nearest to us. Neptune has one satellite, probably as large as our moon, and this satellite moves at a distance of 223,000 miles in a period of 5 d. 21 h. 3 m. Like the satellites of Uranus, it moves backwards, i.e. in a reverse direction to that of the planetary motions. The spectrum of Neptune closely resembles that of Uranus.

112. **The Zodiacal Light.**—This is a faint broad beam of light extending from the sun both ways along the ecliptic or zodiac. After sunset in spring, it may often be seen about latitude 40° N. as a faint cone of light proceeding from the place where the sun has set, and reaching 70° or 80° eastward. In the tropics it has been seen to stretch right across the sky. Its cause is not certainly known. Its spectrum is a faint continuous one. The general idea is that it consists of a ring of meteoric or nebulous matter surrounding the sun in the plane of the ecliptic, and that its light is only reflected sunlight. (For illustration see p. 312).

CHAPTER VII.

THE MOON—ITS DIMENSIONS—ORBIT—ROTATION—PHASES—PHYSICAL CONDITION—ECLIPSES.

113. **Dimensions of the Moon.**—The moon is a satellite of the earth and accompanies it in the journey round the sun. By methods to be afterwards explained, it has been found to be a body having a mean distance from the earth of 238,840 miles. Its mean apparent diameter is 31′ 7″, from which a real diameter of 2,163 miles is obtained. This is equal to 0·273 of the earth's diameter, and as the surfaces of globes are proportional to the squares of the diameters, and their volumes proportional to the cubes, we find that the surface of the moon is a little more than $\frac{1}{14}$ that of the earth, and its volume or bulk almost exactly $\frac{1}{49}$ the earth's volume. Its mass or weight, however, is *only about* $\frac{1}{80}$ that of the earth, so that its density will only be

0·613 of the earth's density, that is 3·4 compared with water. On its surface the force of gravity would only be *one-sixth* the force of gravity on the earth's surface, so that the same force could hurl a body six times higher there than on the earth.

114. **Revolution of the Moon.**—Observation of the situations of the moon on successive nights shows that it daily moves eastward about 13° among the stars, and consequently rises about fifty minutes later each succeeding night. It takes about $27\frac{1}{3}$ days to make a complete circuit of the stars; in other words, the moon revolves round the earth in this time. In reality both the moon and the earth revolve round their common centre of gravity in this period; but so greatly does the earth's mass exceed that of the moon, that this point is about 1,200 miles within the surface of the earth on the line joining their centres. For most purposes we can regard the moon as revolving round the earth in an elliptic orbit. When at its greatest distance the moon is said to be in *apogee*, and when at its least distance in *perigee*, the difference between these two distances being over 26,000 miles. On tracing the moon's path among the stars, its orbit is found to be inclined to the ecliptic at a mean angle of 5° 8′, and the points at which it cuts the ecliptic are called the *moon's nodes*.

115. **Different kinds of month.**—The period of the moon's revolution is the month; but there will be different sorts of months according to the standard by which we judge the revolution. The *sidereal month* is the time occupied by the moon in passing from one star to the same star again. This is equal to 27·32166 days. The moon's average daily motion among the stars will therefore be equal to 360° divided by this number of days, which is 13° 11′ nearly. The *synodic month* is the time occupied by the moon in passing from the sun round to the sun again, i.e. the interval from new moon to new moon again. It is longer than the sidereal month, because the sun is also advancing, though at a slower rate, eastward among the stars, and the moon requires a longer time to overtake it. It varies slightly in length on account of the varying speed of the earth in its orbit (or the apparent varying speed of the sun in its path along the ecliptic). The mean value of the synodic month is 29·53 days nearly, and this is the length of the *ordinary lunar* month. For purposes of civil life *calendar* months are employed. These consist of a certain number of *whole* days—28, 30, or 31, as the case may be. Of such months there are twelve in the year, but in this time there are thirteen lunar months.

116. **Phases of the Moon.**—The different forms or appearances presented by the visible disc of the moon during a

synodic revolution are called its *phases.* The moon's phases are completely accounted for by considering her as an opaque globular body revolving round the earth and shining only by the reflected light of the sun. When the moon is at M_1 (fig. 108) her dark side is turned towards the earth and she is invisible, and it is then said to be *new moon.*

FIG. 108.—The Sun's Globe and the Moon's relative Orbit round the Earth compared.

Proceeding in her orbit round the earth to M_2, she will be seen in the evening sky about 30° to the east of the setting sun, and appear as a crescent, as represented at 2. When the moon has reached the position M_3, her *first quarter,* in about $7\frac{1}{2}$ days, one half of the illuminated portion is turned towards the earth, and she appears to us as half-moon as at 3; when she

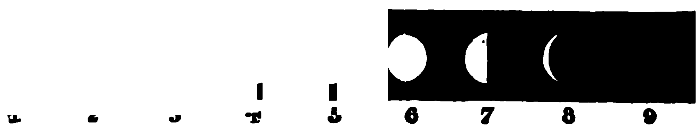


FIG. 109.—Illustrating the Moon's Phases.

has arrived at M_4, more than half the illuminated side is turned towards us, and she is then said to be *gibbous* (humpbacked), as represented at 4. At M_5, when in opposition to the sun, the whole of the illuminated side is turned towards the earth, and the moon appears *full,* as at 5. Continuing her course the moon is now said to wane as she passes through decreasing

light phases; is gibbous at M_6; half-full again at M_7, her last quarter; a crescent, seen in the early morning about 30° to the *west* of the rising sun, at M_8; and in a few days more she comes into conjunction again at M_1 and disappears. The horns of the crescent moon are always turned away from the sun, so that from new moon to the first quarter they point towards the east, i.e. to the left, and from the last quarter to the new moon they point towards the west, i.e. to the right. When the moon is either in conjunction, as at M_1, or in opposition, as at M_5, she is said to be in *syzygy*; when half-way between these points, as at half-moon, she is said to be in *quadrature*. At the phases which immediately precede and follow the new moon, the unilluminated part of its surface is often made visible by the light reflected from the earth's surface, and again reflected from the moon. This reflection of earthshine from the moon is spoken of as 'the new moon with the old one in her arms.' At this time, also, the enlightened part seems to belong to a larger body than the obscure part. This is due to an optical effect called *irradiation*, which makes a bright body on a dark background appear a little larger than it ought.

117. Rotation of the Moon.—As the various marks upon the moon always occupy nearly the same positions on its disc, it follows that the moon always presents nearly the same surface to the earth. From this we conclude that the moon rotates on its axis at just the same rate as it revolves around the earth, or in 27⅓ days. If the reader walk round an object in the room always keeping his face towards it, he will readily see that his body has made a complete revolution, as he has faced every part of the walls in succession. The moon's sidereal day will, therefore, be 27⅓ days, but its solar day will be the time from one new moon to the next new moon, or 29½ days. Daylight and darkness are, then, on the moon's surface about fifteen days in length. The cause of this equality in the periods of rotation and revolution is probably to be found in the earth's attraction when the moon was in a plastic condition. The earth would then raise large tides on its surface, and the bulging mass would be kept towards the earth, and so retard its rotation until it concided with the time of its revolution about the earth. Although the moon continually keeps the same side turned towards the earth, there are certain small oscillations called *librations*, which enable us to see a portion of the opposite hemisphere. Thus while the moon turns on its axis at a uniform rate, its angular velocity in its orbit varies, moving faster near perigee, and slower near apogee. Hence we see a little more of the eastern or western edge at one time than at another time. This is called the *libration in longitude*. Again, the moon's axis is inclined about 1½° to the plane of its orbit, and this orbit is inclined a little more than 5° to the plane of the ecliptic, so that the

northern and southern poles incline alternately $6\frac{1}{2}°$ to and from the earth. In consequence we alternately see a little beyond the north pole and a little beyond the south pole. This variation is called the *libration in latitude*. Finally the daily rotation of the earth carrying the observer to the right and left of the line joining the centres of the two bodies, enables him to see a little further around the right and left sides respectively. This variation in the edges of the moon's disc is called the *diurnal libration*. Taking all the librations into account, we are enabled to see altogether about $\frac{4}{7}$ of the moon's surface.

118. **True form of the Moon's orbit in space.**—The moon is moving round the earth, whilst the earth is pursuing its elliptic orbit round the sun. As a result of this double motion round the earth and with the earth round the sun, the moon's path is a peculiar wavy curve; for half a month it is inside the earth's orbit, and for half a month outside it, crossing the ecliptic at the end of every half-month. But this wavy curve has no intersecting loops, and is, indeed, such that it is always concave to the sun. The diagrams usually employed to represent the phases of the moon and her path round the sun, are on so small a scale that the idea of a path constantly concave is not obtained. If the reader draw a figure on the scale of $\frac{1}{4}$-inch for a million of miles, he may represent the orbit of the earth and the path of the moon for a month with tolerable accuracy.

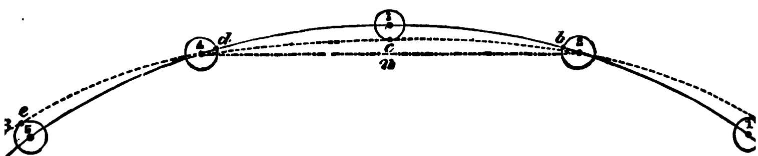


FIG. 110.

With a radius of 92 units (23 inches) draw an arc about 12 inches long for the portion of the earth's orbit (48 millions of miles) described in a month (fig. 110). Divide this arc into four equal parts by dots representing the position of the earth at the end of each week, 1, 2, 3, 4, 5 indicating these successive positions on the arc representing a part of the earth's orbit. Round each dot describe a small circle $\frac{1}{8}$-inch in diameter, to represent the moon's path round the earth, supposing it to be stationary at these points. A small dot at *a* will represent the position of the moon when full, while others at *b*, *c*, *d*, and *e* will represent her successive positions until another opposition. From *a* draw a dotted line through *b*, *c*, *d*, and *e*, and this line will represent the real path of the moon during one revolution round the earth. When the moon is outside the earth's orbit, her path is evidently more concave to the sun than that of the earth's. When inside the earth's orbit it is still concave to the sun, for it can be shown that the sizes of the earth's orbit round the sun, and the moon's round the earth, are such that the radius of the moon's orbit is less than half the distance from 3 to the chord, or straight line joining *b* and *d*. Thus the moon's real orbit is simply the earth's orbit with 25 alternate slight elevations and depressions of its concavity towards the sun at each full and new moon, the moon in thus moving in and out also crossing the earth's path round the sun 25 times; for there are nearly $12\frac{1}{2}$ synodic revolutions or lunations in a year.

119. **The Daily Retardation of the Moon's rising and setting.**—On each succeeding night the moon rises, passes the meridian, and sets later than on the previous night. The average daily retardation of all three is about 51 minutes. But in the cases of rising and setting, which depend in part on the moon's changes in declination, there are great variations of the retardation. In some parts of the year the retardation is much smaller than the average, at other parts much larger. The extent of these variations differs also according to the latitude of the observer, being greater the further from the equator.

120. **Harvest Moon.**—In the northern hemisphere that full moon which occurs nearest to the autumnal equinox, September 23, is called the Harvest Moon. At this period the retardation of the moon's rising is least, because her orbit is at this time least inclined to the horizon, so that on several successive nights, a full, or nearly full, moon rises at nearly the same time, viz. sunset. Hence the name harvest moon because it occurred near the end of harvest, and its light was useful to finish off the last operations of harvest. In the southern hemisphere the harvest moon is the full moon nearest their autumnal equinox, i.e. nearest March 21.

121. **Perturbations of the Moon's Orbit.**—The path of the moon round the earth is continually affected by disturbing forces. The chief of these is the powerful attraction of the sun. A complete lunar theory—that is, one which will take account of all perturbations so fully as to exactly predict the moon's position for any future time—is not yet developed; though the skill of mathematicians has reduced nearly all these perturbations to order and calculation. We shall indicate two of these disturbances of the moon's path. It is convenient in all cases to consider the moon's path as an ellipse round the earth; but that ellipse is liable to changes in its form and position.

122. **Revolution of the Line of Apsides.**—This is the line joining the apses, or it is the major axis of the ellipse, and joins the points of perigee and apogee. One consequence of the disturbing effect of the sun is to make this line advance in the same direction as the moon itself moves. It is, as it were, not only the moon which moves round the earth in an ellipse, but the ellipse, regarded as a hoop, swings round the earth, which is at its focus, in the same direction but much more slowly. There is not a steady motion of the line of apsides; it is sometimes an advance and sometimes a regression, but an advance on the whole. The period of revolution is about 9 years (8·855 years).

123. **Revolution of the Moon's Nodes.**—The nodes, as previously stated, are the points at which the moon's orbit intersects the plane of the ecliptic. These two points, in consequence of perturbations, have a motion of regression, *i.e.* a backward movement in the opposite direction to the moon's motion in its orbit. The rate at which the nodes regress is very variable; the period for a full revolution is about 19 years.

124. **Lunar periods—the Saros and Metonic Cycle.**—As the nodes of the moon's orbit are not stationary, but have a

daily retrograde motion, the moon performs a revolution with respect to the node in less time than it performs a sidereal revolution, and in still less time than it performs a synodic revolution. The *nodical* revolution of the moon is made in 27 d. 5 h. 6 m.; the *sidereal* revolution in 27 d. 7 h. 43 m.; and the *synodic* revolution in 29 d. 12 h. 44 m. There is also a synodic revolution of the node, which is the time during which the node comes into the same position with respect to the sun, and this is 346·62 days. Now 19 synodical revolutions of the node ($346{\cdot}62 \times 19$ days)=6,585·78 days, and 223 lunations or synodical revolutions of the moon ($29{\cdot}53 \times 223$ days)= 6,585·32 days. These two periods are both equal to 18 years 11 days nearly, and this interval is known as the *saros*. It is the lunar cycle by means of which eclipses were roughly predicted before more exact calculations could be made; for at the end of the first period the sun and the moon's node would be situated alike, and at the end of the second period the sun and moon would be situated alike. If, therefore, an eclipse occur at the beginning of the *saros*, one will also occur at the end of it, and all the eclipses of one period will be found approximately to repeat themselves in the next. Another lunar cycle is called the *metonic cycle*. It is a period of 19 Julian years.

235 synodic months=6,939·69 days
19 ordinary years ($365\frac{1}{4}$ d.)=6,939·60 days

a difference of only about 2 hours.

This shows that after 19 years the sun and moon are back in the same relative positions, and that after 19 years the phases of the moon will recur on the same day of the same month. From an ancient Athenian custom of inscribing the dates of these phases in letters of gold on the public monument, the number which marks the rank of any year in the metonic cycle is called the *golden number*. The year 1 B.C. begins the cycles now in use. Hence, to find the place of a given year in the lunar or metonic cycle, add one to the number of the year A.D., and divide by 19, the remainder (or 19 if exactly divisible) is the golden number of the year. Thus for 1890 the golden number is 10.

125. **Telescopic Features of the Moon's Surface.**—Viewed with the naked eye, the moon shows inequalities of surface, dark and light patches of various shapes being easily visible. But when examined by a good telescope the meaning of these

various shades soon becomes apparent, and many curious details of its surface can be made out. The dusky portions once supposed to be *seas*, and still spoken of as such, are in

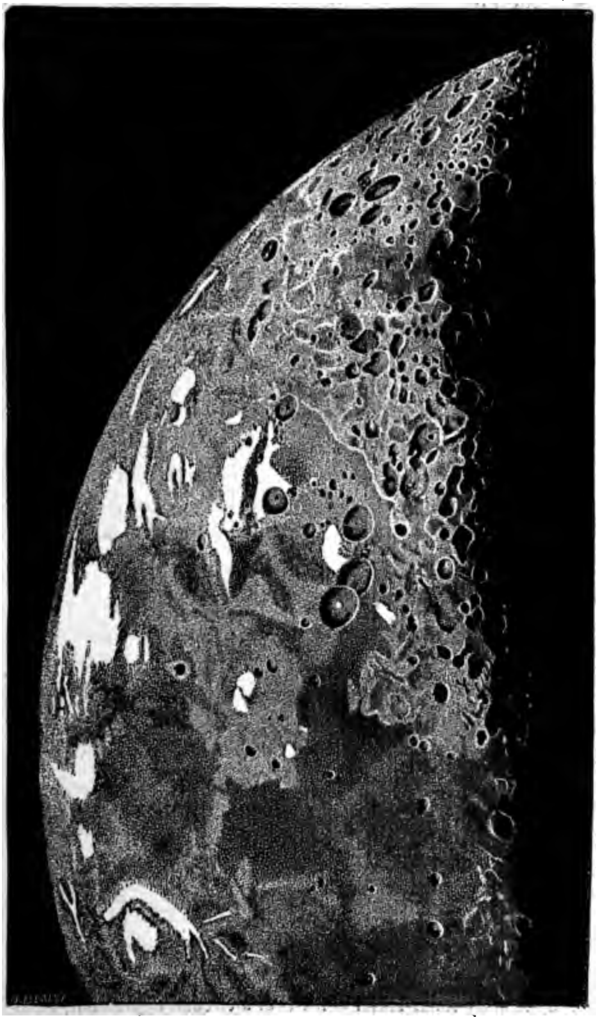


FIG. III.

reality great plains, while the brighter parts are the lunar mountains. The moon's surface is best studied a little before, or a little after, the time of half-moon, for then, the sun shining obliquely on our satellite, the shadows of the high peaks may be seen cast on the surrounding plains; and the *terminator*, or boundary line of the illuminated part, presents an irregular, jagged appearance, owing to the summits of the mountains receiving the sun's light, while the slopes and valleys are still in the shade. At full moon the shadows disappear, as the sun is then shining perpendicularly down on the moon's surface.

Fig. 111 illustrates the telescopic appearance of the moon a little before the first quarter. So carefully has the moon's surface been studied in large telescopes that virtually bring it within a range of 500 miles, and so frequently have excellent photographs of its surface been obtained, that very accurate maps have been made, and all the principal objects classified and named. Of the twelve large grey plains called 'seas,' Oceanus Procellarum, Mare Imbrium, Mare Fecunditatis, Mare Serenitatis, and Mare Tranquillitatis are the chief. These 'seas' are thought by some astronomers to be old sea-bottoms, the water having disappeared ages ago, by entering into combination with the minerals of the crust. They appear dark because the matter now forming their surface reflects less of the sun's light than other parts of the moon's surface.

126. **Crater Mountains.**—The crater mountains are the most curious feature of the moon's surface. These are found on all parts and resemble

FIG. 112.—A Typical Lunar Crater.

the craters of our volcanoes, though many of them are on a much larger scale. An ordinary lunar crater consists of a circular depression, often fifty

sixty miles across, surrounded by an elevated ring of mountains rising
›m two to twenty thousand feet high. These circular hollows have fre-

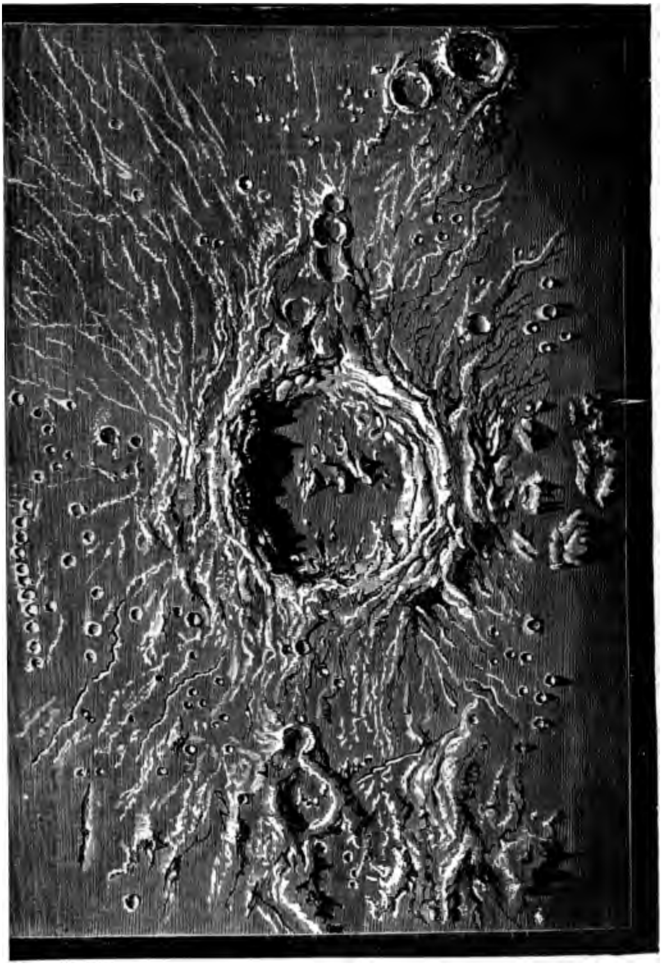


FIG. 113.--The Lunar Crater Copernicus, from a drawing by Nasmyth.

ently flat floors, sometimes above and sometimes below the outside level,
om the middle of the crater there often arises one or more conical peaks,

at the top of which smaller holes, or craterlets, have been in some cases detected. The largest of the crater-shaped mountains are spoken of by some authors as *walled plains*. These, in some cases, are more than 100 miles in diameter, and one of them, called Newton, is surrounded by ramparts 23,000 feet high. Fig. 113 represents the lunar crater Copernicus, as seen in a powerful telescope shortly after sunrise on the mountain. Thus the left-hand side of the crater wall casts its shadow on the floor, the irregularities of the shadow being caused by the variations of height of the wall. The crater is fifty-six miles across, the wall is in parts 11,000 feet above the floor, which is considerably below the general surface outside, and one of the central mountains is 2,400 feet high. The surrounding wall really consists of more or less complete concentric rings separated by ravines and chasms. Many smaller craters are seen outside the large crater. Other large craters are Plato, Archimedes, Kepler, Gassendi, Tycho, &c. All indications of volcanic action appear to have ceased on the moon, though some observers think that small changes are still going on.

Besides the ring mountains there are mountain chains and many detached peaks on the moon's surface; but the mountain chains are relatively insignificant compared with those on the earth, while the craters are far larger and relatively more numerous. The heights of the lunar mountains have been calculated from the lengths of the shadows cast by the peaks at the time they first appear as spots of light at their sunrise.

Rays and Rills.—*Rays* are light-coloured streaks radiating from certain of the craters at a distance of several hundred miles. As they seem to pass in some cases beneath the mountains, they are probably older than the craters and may possibly represent rifts or fissures in an early lunar crust filled up by lighter-coloured matter from below, like 'trap-dykes' on the earth. The most remarkable system of rays is that passing from the great crater Tycho not far from the moon's south pole. *Rills* are clefts or furrows extending in a straight line for long distances and passing through mountains, craters, and valleys. They may be regarded as deep cracks in the moon's crust, and are plainly of later formation than the crater, which they intersect. Crater-mountains, rays, and rills all point to a past period of great internal activity on the moon, 'when volcanic action even more effective (though not probably more energetic) than any which has ever taken place on this globe upheaved the moon's crust.' That the moon is at so much later a stage of planetary life than the earth, supposing it to have been formed at the same time as the earth, or even to have been thrown off from the earth, as some writers believe, is easily understood when we bear in mind the relative size of the two globes. The mass of the earth is eighty-one times that of the moon, but its surface only $13\frac{1}{2}$ times as large, and hence the earth must have cooled through its various stages at a much slower rate, in fact about six times ($81 \div 13\frac{1}{2}$) more slowly. That the moon is now an airless, arid, and lifeless globe, a mere dead and barren mass of rock, seems certain.

127. **No Atmosphere and no Water on the Moon.**—The best proof of the absence of an atmosphere is the absence of the slightest indication of refraction at the moment when the limb of the moon passes between the earth and a star. At such *occultations* of the stars, the stars disappear instantaneously,

reappearing quite as suddenly.[1] This can be shown to indicate a refractive power of less than $\frac{1}{8000}$ part that of the earth. Further, there is no evidence of any kind of distortion or haze near the edge of the disc, and no indication of clouds or any atmospheric phenomena. Without an atmosphere of air there can be no water on the surface of the moon, since the water would evaporate to form an atmosphere of its own vapour, and this could be readily detected. Further, the spectroscope shows that the light of the moon is reflected sunlight, pure and simple, no trace of any absorptive effect being discernible. If the moon ever had an atmosphere, as is probable, and as indeed it must have had if it was ever united to the earth, this atmosphere must have been absorbed into the cold rocks now forming its mass.

128. **Light and Heat of the Moon.**—The moon has been found to reflect a little more than one-sixth of the sunlight that falls on its surface, the average albedo, or reflecting power, being 0·174. Its *brightness* as compared with sunlight is given by Zöllner as $\frac{1}{618000}$. This shows that if the whole of the visible hemisphere were covered with moons, they would only give about $\frac{1}{8}$ the amount of the light of the sun. The heat reflected by the moon, and radiated off after being absorbed from the sun, is so small that it cannot be detected by the most delicate thermometer. By the aid of the thermo-electric pile, an instrument in which a very small quantity of heat starts a current of electricity, and using a reflecting telescope to concentrate the lunar rays, the heat given off from the moon has been rendered evident. At full moon the lunar heat has been estimated at $\frac{1}{185000}$ part of that received from the sun. On the moon's surface itself there must be an enormous change of temperature according as it is turned towards or from the sun. When the sun is not shining, the temperature must fall two or three hundred degrees below zero, for there is no air blanket to check immediate radiation. Even on the sun-lit surface Professor Langley concludes that the temperature is only about 0° C.

129. **Eclipses.**—A large, self-luminous, spherical body like the sun shines in all directions, and its light falling on the much smaller bodies known as planets, long conical shadows, tapering to a point, are cast behind them in the spaces where this light is entirely intercepted by their opaque globes. When the source of light is not a mere point, but of sensible diameter, there is also on each side of the dark shadow, a fainter one caused by a partial interception of the light. A body entering

[1] Occultation (Lat. *occultare*, to hide) is the term applied to the concealment of the stars by the moon as it moves eastwards, or to the concealment of Jupiter's satellites behind the disc of their primary.

into a shadow is said to suffer an *eclipse*. An eclipse of the moon is caused when she enters the shadow of the earth; that is, when the earth passes between the sun and moon. This can only occur when the moon is in opposition—that is, at the time of full moon. An eclipse of the sun is caused by the moon passing between the earth and the sun, so that the shadow of the moon falls on the earth. It can, therefore only occur when the moon is in conjunction, or nearly in conjunction, with the sun—that is, at the time of new moon. If the moon's orbit coincided with the plane of the ecliptic, we should have an eclipse of the moon at every full moon, and an eclipse of the sun at every new moon. But the moon's orbit is inclined to the ecliptic about 5°, and an eclipse can therefore only happen if at these times the moon is also at or near one of its nodes. At other times the moon is either too far above or below the earth's path for one body to enter the shadow of the other. As the motions of the earth and moon are accurately known, the relative positions of sun, earth, and moon, at any time can be predicted, and the hour and place of an eclipse determined by calculation.

130. **Lunar Eclipses.**—By the help of fig. 114 we shall be able to understand an eclipse of the moon. In fig. 114, where S represents the sun

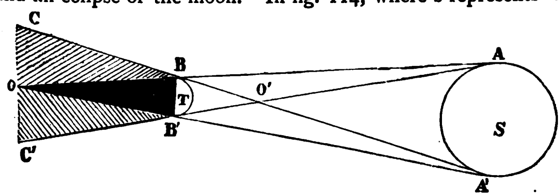


FIG. 114.

and T the earth, the two tangents A B and A′ B′ meet at O, and the black cone B O B′ seen in section shows the space within which no light falls, this central dark shadow being called the *umbra*. The tangents A B′ and A′ B mark out two diverging spaces (or rather a conical space having C′ for its vertex) where only partial sunshine is received, this lighter shadow being called the *penumbra*. If the moon in its revolution round the earth enters the penumbra, a partial loss of the sun's rays occurs, but this is so slight as to be hardly perceptible. As the moon enters the umbra, a notch seems to be cut out of it, the edge of the earth's shadow being always circular. In a *partial* eclipse this darkened portion increases to a certain size and then grows less till the eclipse is over. In a *total* lunar eclipse *the whole of the* moon gradually passes into the umbra. As the breadth

of a section of the earth's dark shadow at the distance of the moon is on the average about three diameters of the moon, the duration of *totality* when the moon passes through the axis of the shadow may be nearly two hours, since it moves eastward faster than the earth through a space equal to its own diameter in an hour. When totally eclipsed, the whole disc of the moon is often faintly visible, shining with a dull red light. This is due to the refractive power of the earth's atmosphere, which bends some of the sun's rays into the dark shadow and thus brings them on the surface of the moon. The light which thus reaches the moon is red, because the other colours of sunlight have suffered absorption in passing through a great thickness of the earth's atmosphere. Since the moon and the earth's shadow both move from west to east, in consequence of the orbital motion of the two bodies, and since the moon's motion is the more rapid, the moon will pass through the earth's shadow from west to east, the eclipse beginning on its eastern limb. On account of the relative size of the earth, and the distance of the moon, the length of the earth's dark umbra is always three or four times greater than the moon's distance, and hence the moon will always pass entirely into the umbra if at the time of opposition it is at its node. If the moon is some distance from its node, there will only be a partial eclipse, the amount of surface eclipsed depending on its distance from the node. If north of the node its lower portion only may be darkened; if south of the node, the upper portion may catch a part of the earth's shadow. If the moon is more than 12° from its node, no portion of its surface will suffer eclipse. A lunar eclipse being caused by the earth's shadow depriving the moon, or a portion of the moon, of its actual sunlight is visible at every place which has the moon above the horizon during the time that the light is thus cut off.

131. **Solar Eclipses.**—It will readily be understood that the dark shadow cast behind the moon can only fall upon the earth when the sun, moon, and earth happen to be in a straight line with the moon in the middle. They can only be in such a straight line when the new moon is at or near one of its nodes. Even then it does not follow that the eclipses of the sun will be total on any part of the earth, for the length of the moon's conical shadow is at the greatest only 236,000 miles, while the mean distance of the moon is 238,000 miles. Owing, however, to the eccentricity of the moon's orbit, our satellite is often considerably within the mean distance, and about the time of perigee its umbra may reach the earth's surface, causing a total eclipse to the inhabitants of that part on which it falls.

The part of the earth involved in total darkness is always very small, as the diameter of the cross-section of the shadow where the earth cuts it cannot exceed 167 miles; but the penumbra, within which the eclipse is *partial*, may extend over an area of that hemisphere turned towards the sun of more

than 200 miles in radius. The lunar cone shadow marks out on the earth's surface as the moon moves on its orbit a narrow track, within which the eclipse is total. The time during which totality lasts at any one place can never be more than a few minutes, and is sometimes only a few seconds, the length of

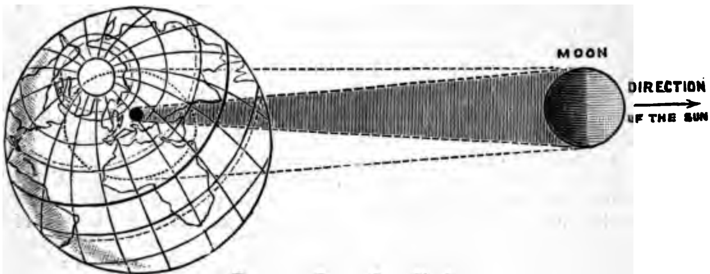


FIG. 115.—Lunar Cone Shadow.

time depending on the area of the dark shadow that reaches the earth, that is on the distance of the moon at the time. In fig. 116 we have a diagram of an eclipse of the sun; A B representing the moon's monthly path round the earth, and M the moon at the time of conjunction.

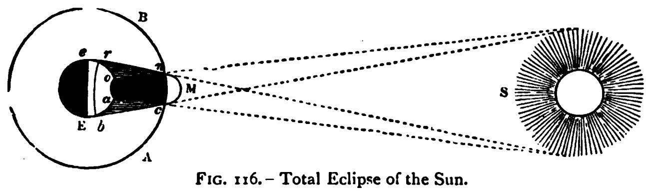


FIG. 116.– Total Eclipse of the Sun.

To an observer within the dark shadow *a* to *o* on the earth's surface the sun will be totally eclipsed. On either side of this, in the parts covered by the penumbra or lighter shading, *o* to *r* and *a* to *b*, there will be a partial eclipse.

132. **Annular Eclipses of the Sun.**—When the moon is near apogee at the time of a solar eclipse, her diameter subtends a less angle than that of the sun, and her conical shadow does not reach to the earth. No total eclipse can then happen at any part; but at a place in a line with the point of the shadow, the central part of the sun will be eclipsed while a luminous ring will be seen all round the dark body of the moon. This is called an annular (L. *annulus*, a ring) eclipse of the sun. An annular eclipse of the moon is impossible, because at its distance the diameter of the earth's shadow is always greater than the diameter of the moon.

133. **Frequency of Eclipses.**—Eclipses of the sun are more frequent than eclipses of the moon, because the sun's ecliptic limits, i.e. the distance from the nodes ($18\frac{1}{2}°$) within which an eclipse may occur, are greater than the moon's ecliptic limits ($12°$). Yet at any one place more eclipses of the moon are visible, because eclipses of the sun are only visible on those portions of the earth where the shadow of the moon falls, whilst eclipses of the moon, due to her actual loss of light, are seen over the whole hemisphere that has the moon above its horizon at the time its light is cut off. The least number of solar eclipses that can occur in a year is two, and the greatest number is five. No lunar eclipse may happen in a year and there may be three. The greatest number of eclipses of all kinds in a year is seven and the least number two. When there are seven, five of them are of the sun and two of the moon; when there are but two, both are of the sun.

134. **Phenomena observed during a Total Solar Eclipse.**—A total eclipse of the sun is described by those who have been fortunate enough to observe one, as a grand and imposing spectacle. Nothing special is noticed until the greater part of the sun's disc is covered, but a few minutes before it is entirely obscured, the crescent of sunlight becomes so narrow that a strange darkness is felt creeping on, and objects acquire a livid and unnatural hue. Nature appears disturbed, birds go to roost; flowers close; and a perceptible decrease of temperature takes place as the time of greatest obscuration draws on. If the observer be on a high mountain, the moon's shadow is now seen sweeping upward through the air from the western horizon with great velocity, and in a few moments he is enveloped in it. The darkness, coming thus suddenly and abruptly at the last, is not so great as is sometimes imagined, though it is sufficiently intense for the brighter stars and planets to be clearly seen. At the same time round the black body of the moon the sun's surroundings become visible—the fiery-red chromosphere with its prominences, and the more extended but fainter halo of light known as the corona. Professor Langley, who has witnessed three total solar eclipses, says: 'Nearly everyone, then, has seen a partial eclipse of the sun, but comparatively few a

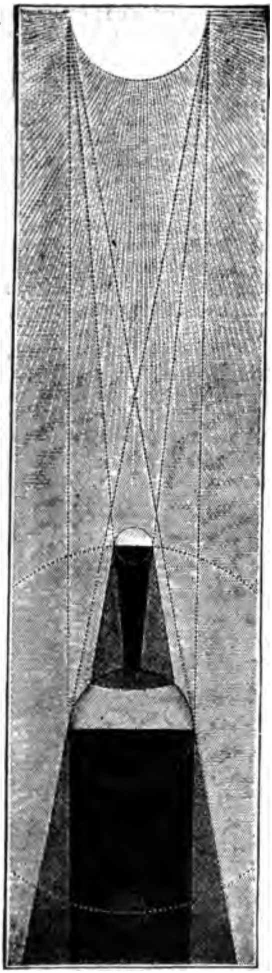


FIG. 116 *a*.—This figure (from Brinckley's Astronomy) is intended to exhibit the effects of the shadow of the moon in causing an eclipse of the sun, and of the shadow of the earth in causing an eclipse of the moon.

total one, which is quite another thing, and worth a journey round the world to behold; for such a nimbus, or glory, as we have suggested the possibility of, does actually exist about the sun, and becomes visible to the naked eye on the rare occasions when it is visible at all, accompanied by phenomena which are unique among celestial wonders.

'The "corona," as this solar crown is called, is seen during a total eclipse to consist of a bright inner light next the invisible sun, which melts into a fainter and immensely extended radiance (the writer has followed the latter to the distance of about ten million miles), and all this inner corona is filled with curious detail. All this is to be distinguished from another remarkable feature seen at the same time; for close to the black body of the moon are prominences of a vivid crimson and scarlet, rising up like mountains from the hidden solar disc, and these are quite distinct from the corona, though seen on the background of its pearly light.' The chromosphere, prominences, and corona have already been described in Chapter V.

It is to study the nature of these surroundings of the sun that astronomers travel thousands of miles to get into the central track of a total eclipse. Their observations at the most can only last seven minutes, and the time is often less, for the shadow passes on with nearly the speed of the moon in the sky, tracing out a narrow strip which curves across the hemisphere turned towards the sun, until it passes off the earth. The next total eclipse of the sun will occur on December 12, 1890, and the central track will pass between Australia and the South Pole. On April 26, 1893, there will be one visible over a belt in the Pacific Ocean. No total eclipse of the sun will be visible in any part of England until June 29, 1927, though one may be seen in Norway on May 9, 1896.

CHAPTER VIII.

THE TIDES.

135. THE regular rise and fall of the waters of the ocean, at any place on the sea-coast, are called *tides*. The risings and fallings occur on the average twice each in every 24 hours 51 minutes. The extent of the rise and fall varies greatly at different places, as also do the times at which high and low water occur. But even at the same place the extent of the rise varies from day to day; twice in every four weeks there occurs an extra high tide, and twice an extra low one. The coincidence of these two periods, the 24 hours 51 minutes, and the four weeks, with the interval of two successive meridian passages of the moon, and with the lunar month, point to the close connection of the moon and the tides.

136. Causes of the Tides.—The moon is the chief agent in causing the tides. The action may be thus explained: E represents the earth supposed to be quite covered with water, M the moon attracting the solid earth and the water over its surface. Its attraction immediately under it is greater than its attraction on the slightly more distant solid earth. Hence it attracts the water more strongly, and drawing it away from the earth, heaps it up around A, causing high water under the

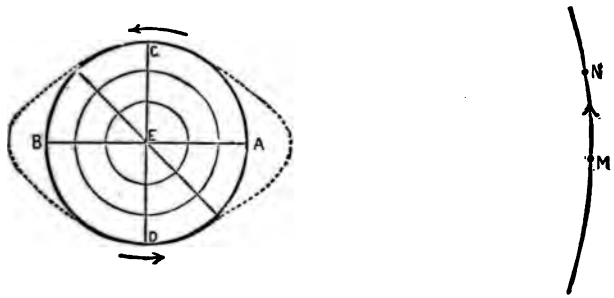


FIG. 117.

moon. Similarly it attracts the solid earth more strongly than it does the water on the far side of the earth. Hence it draws the earth away from the water round B, and leaves the water there heaped up; causing another high water at the opposite side of the earth. So that there are two positions of high water, one under the moon at A, and the other at the opposite side of the earth at B. At the positions half-way between these, as C and D, there will be low water, compensating for the high-water levels at A and B. It must be distinctly understood that it is not sufficient to say that the attraction of the moon causes the tides. The true cause is the *difference* of the attraction of the moon on the solid earth, and on the water nearest and farthest from itself. The sun has a similar effect to the moon in causing a tide. But in spite of the sun's greater attractive power, it is so much farther away (about 310 times) that its tidal effect is only about *two-fifths* of that of the moon. It can be mathematically proved that the tide-producing effect varies directly as the mass and inversely as the cube of the distance of the tide-producing body.

If the solar and lunar tides coincide, there will be an increased tide, due to their sum; if the high water from the one coincides with the low water from the other, the resulting tide will be a smaller one, due to the difference of the two. As the lunar tide is so much the larger, we can look on it as the actual tide, the solar tide merely modifying it in such ways as will be pointed out.

137. **The Statical Theory of the Tides.**—If the earth and moon were at rest, the high tides would be permanent at A and B directly under and opposite the moon; and there would be low water all round the circle of the earth passing through C and D, at all places equidistant from A and B. Even with a rotation of the earth in the direction of the arrows in the figure, it would seem that every place arriving near A or B would then have high water, whilst near C or D it would have low water. This is equivalent to saying that a tidal wave would move round the earth from east to west (opposite to the earth's direction of rotation), at such a rate as to keep the crest of the wave under the moon. But the inertia of the water would make it drag behind the moon, so that it always followed it, rather than kept directly under it. But again, the varying depths of the ocean and the irregular forms of the shores would totally alter this tidal wave, giving most complicated results. This statical theory, in fact, is quite unsatisfactory so far as actual events are concerned. It is, however, suitable in connection with observations on actual tides for explaining their general theory.

138. **Daily Changes of the Tides.**—Referring to the figure (117), we see that each place on the ocean twice daily, by the rotation of the earth, is carried through the positions of high and low water. But the interval of a complete change is not the twenty-four hours required for the rotation of the earth. It is rather more, for while the earth is turning round once, the moon moves on in its orbit round the earth from M to N, so that the earth has to turn a little farther for a given place to overtake the moon and come to a position of high water. The interval for the tides will be much the same as the interval of successive meridian passages of the moon, so that the interval then between corresponding tides in successive days is on the *average* 24 h. 51 m. In that period there are two high tides

and two low tides. When the water is rising it is *flood* tide, when falling it is *ebb* tide; when the tide is at its highest it is *high water*, when lowest it is *low water*.

139. **Fortnightly Changes: Spring and Neap Tides.**—At intervals of a fortnight there are high tides which rise higher

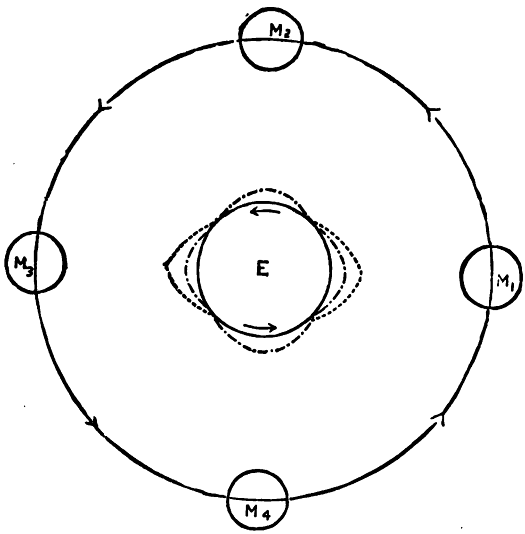


FIG. 118.

than usual, and between these others not so high as usual. The cause of these fortnightly changes is the joint action of sun and moon as tide-producing bodies. Fig. 118 represents these effects. E is the earth, M_1, M_2, M_3, M_4, four positions of the moon at intervals of a week; the sun is away on the right. The motions of the bodies are represented by arrows, and the tides by the dotted lines round the earth. When the moon is at M_1 or M_3, i.e. at new or full moon, the sun's tide-producing force is added to that of the moon, and together they produce the highest tide. These extra-high tides are called *Spring Tides.*

When the moon is at M_2 or M_4 in the first and third quarters lunar high water corresponds to solar low water, and the resultant effect *is a tide not so high* as usual. These smaller tides are

called *Neap Tides.* Spring tides are then the highest in the month, and neap tides the lowest.[1]

Priming and Lagging of the Tides.—A further result of the disturbing effect of the solar tide on the larger lunar tide is a change in the interval between successive tides. Instead of high water occurring under the moon, it is made to occur on a meridian rather nearer to the sun. At the time of spring tides the intervals are rather shorter than the average, being only about 24h. 38m. This is the *priming* of the tides; but at neap tides we get a *lagging*, the interval being greater, about 25h. 6m.

140. **Tides in relation to Moon's Age.**—1. At new moon the sun and moon are in conjunction, the moon's age is 0 days: it passes the meridian at the same time as the sun, and spring-tides occur.

2. At the first quarter the moon's age is 7½ days: it passes the meridian 6h. later than the sun, and neap tides occur.

3. At full moon, the moon is in opposition, its age is 15 days: it passes the meridian twelve hours later than the sun, and spring-tides again occur.

4. At the last quarter the moon's age is 22½ days: it passes the meridian 18 h. later (or 6 h. sooner) than the sun, and neap tides again occur.

141. **The Establishment of a Port.**—At every port it is observed that high-water seems to follow the moon's meridional passage by a certain interval of time. This interval varies greatly for different ports, but is fairly constant for the same port, and, once known, is very useful for purposes of foretelling the time of high-water at that particular port. It is called *the establishment of the port*, and is the mean interval between the time of high-water and the preceding meridional passage of the moon. How very much it varies for different ports will be understood later in the discussion of the actual occurrences of tides and co-tidal lines. For example, at Gibraltar it is nearly zero; at Dunkirk nearly 12h.; at New York it is 8h. 13m.

142. **Other periodic Variations in the Tides.**—Solar and

[1] As the lunar tide-producing force is to that of the sun nearly in the proportion of 5 to 2, the relative height of the spring and neap tides will be as about 7 to 3 (i.e. $5+2$ to $5-2$).

ıar tides are greatest when the sun and moon are nearest to e earth, and when they are most directly over the equator. rst, then, the heights of spring and neap tides will vary cording to the nearness or remoteness of the moon and sun. he greatest and least distances of the moon from the earth e as 8 to 7; of the sun from the earth as 30 to 29. Though e sun is nearest on January 1, it is then far from the equator. ut for the new and full moons which occur near the equinoxes March 21 and September 23), with both the sun and moon early vertically over the equator, there are unusually high tides nown as equinoctial spring tides.

143. **The Wave Theory of Tides.**—The previous explanation f the *cause* of the tides is sufficiently correct, but by no means ccurately indicates the real tidal effects that are observed. The simple theory would indicate two tidal waves moving from ast to west at such a rate as to accomplish the journey round he earth in 24h. 51m., the crests of the wave being under the noon and on the opposite side of the earth to the moon, or, at ny rate, close to these portions. But such considerable effects re produced by the variation in ocean depth by shoals and by he configuration of the continents that all this is changed. In he Atlantic Ocean, for instance, the tidal wave advances from outh to north; and near the western coast of Europe, indeed, noves eastward rather than westward. Careful observations at nany stations are needed to fully understand these peculiarities. *Co-tidal lines* are lines drawn on the surface of the ocean through ll places that have high water at the same moment of Greenwich me. They indicate the crest of the tidal wave for each hour, nd if they could be laid down with certainty for the whole cean surface, we should have all the information we need bout the motion of the tidal wave. Unfortunately, this cannot e done, for observations in mid-ocean cannot be made, and e only have them for islands and coasts. So that these tidal nes are in part guesswork. Nevertheless, near such a coast s the English, observations are frequent, and the co-tidal lines onsequently accurate. A map showing the co-tidal lines for he British Islands is inserted on page 295.

144. **Course of the Tidal Wave.**—From a map of the tidal

lines of the whole world, it would seem that a main wave starts twice a day in the Southern Pacific, off Callao in South America. This is the most natural source for the tidal wave to start from, for it is in this part of the world that the extent of ocean subject to tidal influence is greatest. From this starting-place the wave spreads out over the Pacific. It must be remembered that there is no actual transfer of water like there is in a river or in the Gulf Stream; but the mere up-and-down motion which constitutes a wave. The rate of the wave in crossing the sea depends on the depth of the water. The parent wave, starting off Callao, moves off north-west through the deep Pacific at about 850 miles per hour, reaching Kamschatka in ten hours; westward and southward through a shallower portion, it travels slower, from 400 to 600 miles per hour, reaching New Zealand in about twelve hours. Passing Australia it combines with the small tide which the moon directly causes in the Indian Ocean, and passes the Cape of Good Hope in about twenty-nine hours. It then enters the Atlantic and combines with the wave which has preceded it by twenty-four hours round Cape Horn; and also combining with the direct tide of the Atlantic, travels northwards at about 700 miles per hour. The co-tidal lines are here arched northwards, the central parts travelling faster, the sides being dragged back by the American and African coasts. It is forty-one or forty-two hours old at New York. On the British Islands it is broken up, part proceeding up the English Channel, part rounding Scotland and coming down into the North Sea. The London tide coming from the North Sea round Scotland is about sixty hours old; about the same as for the ports on the German Ocean. The tidal wave sweeps eastward on to Norway and round the North Cape into the Arctic Ocean. There are then three or four wave-crests travelling across the large oceans, existing simultaneously and following the same track. Whilst up estuaries, as in the mouth of the Amazon, the wave-crest travels slowly, and may be three or four days old from its original start in the Pacific.

145. **Height of Tides.**—In mid-ocean the tidal undulation is *only* about two or three feet high, as shown at isolated islands

like St. Helena. But on continental shores with a shallow depth of water, the wave travels slowly and heaps itself up higher. In mid-ocean the water has no onward motion, but near the land the rising tide floods the bays and flats around, running out again at the ebb. The tidal currents have a velocity quite different from that of the tidal wave itself. If the tide rushes into a funnel-shaped estuary or bay, it may heap itself up to a great height at the top of the bay. For instance, in the mouth of the Severn near Bristol there are tides of fifty feet, though on the opposite Irish coast the rise is about two feet; while in the Bay of Fundy tides of seventy feet are fairly common, and with a favourable wind even 100 feet is attained.

146. **Tidal Bores.**—Sometimes the tide ascends a river like the Severn, Seine, and Amazon in a great wave called a *bore*, with an almost vertical front of some few feet in height. This tidal phenomenon is due to the fact that the wide estuary at the mouth contracts like a funnel, and causes the inflowing tidal water to accumulate as an advancing ridge. On the Hooghly branch of the Ganges, the bore travels 70 miles in four hours, and is often seven feet high.

147. **Tidal Interference.**—The coasts of the British Isles afford many instances of tidal interference. For example, on our east coast the tide waves come round both from the north end of Scotland and from the Straits of Dover. These waves so interfere with or aid one another as to produce a tide of nearly double the height at one place; at other places not far away there may be hardly any tide; whilst at others, again, there may be even four distinct high waters in one day.

148. **Tides in Inland Seas and Lakes.**—These are very small. Even in the Mediterranean the tidal rise and fall is only about eighteen inches, or at the highest, in some bays, three or four feet. On the great fresh-water lakes of America, a very small tide of an inch or two has been detected; but variations in the wind and barometric pressure cause greater deviations of level than these true tides.

149. **Masses of the Sun and Moon calculated from the Tides.**—The spring tides are caused by the sun and moon

conjointly, and the neap tides by the difference of their attractions. Hence we can infer the relative amounts due to sun and moon respectively; and if we know their distances we can calculate their relative masses, so that they shall have this tide-producing power.

150. **Effect of the Tides on the Earth's Rotation.**—The tides, in their westward and forward flow, show a considerable store of energy. Whence is this energy deduced? It has been shown to be an abstraction from the earth's rotational energy. In fact the tides moving westward act as a break on the earth rotating eastward. So they are gradually, by their friction, lengthening the period of rotation or the length of the day; but the change is extremely slow—not so much as the $\frac{1}{1000}$ part of a second in 1,000 years.

151. **Effect of the Tides on the Moon's Motion.**—The tides not only reduce the earth's rotational energy, but transfer a small part of it to the moon. The explanation of this, though not simple, is quite certain by mathematical methods. The consequence is to increase the velocity of the moon and then to increase the size of its orbit, so that the moon is retreating and formerly was closer than now. From these actions of the tides on the earth and moon Professor G. H. Darwin has deduced his theory of Tidal Evolution.[1] This states that our moon, and the satellites of other planets, started from the planets and were driven out to their present positions by the action of the tides. A popular account of the theory will be found in Dr. Ball's 'Time and Tide.'

CHAPTER IX.

COMETS AND METEORS.

152. **General Appearance of Comets.**—The word *comet* (Gr. *kome*, hair) really means hairy star, and these bodies are so called because, when visible to the naked eye, the appearance

[1] See note in Appendix.

is usually that of a misty star carrying with it a streaming train of faint light. They only become visible for a comparatively short time, and after describing a longer or shorter path among the stars, disappear from sight. The two parts referred to are usually spoken of as the *head* and *tail*. The head itself, however, often consists of two portions—a central bright portion called the *nucleus*, and a surrounding fainter part, of spherical or oval shape, called the *coma*. The tail consists, when present, of a train of dimmer light flowing from the head, and always turned away from the sun. When first descried in the telescope at a great distance from the sun, comets appear simply as round, nebulous-looking bodies, the nucleus being hardly discernible. As they approach the sun in their orbital motion, the tails, as a rule, begin to appear, increasing in length as they get nearer; and in some cases the nucleus at this approach is seen to emit jets or streamers of light, and to throw off a series of shells or layers which expand outwards. This development of jets and envelopes is usually accompanied by changes in the brilliancy and magnitude of the nucleus. After passing round the sun, the activity of the nucleus abates as the comet recedes, and when followed to a great distance by the telescope, the object passes again into a mere misty disc. In some cases two or three nuclei have been seen, while in some of the smaller comets neither nucleus nor tail appears, and the comet is then a mere 'patch of foggy light of more or less irregular form.'

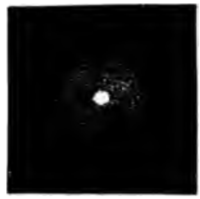


FIG. 119. - Donati's Comet on June 2, 1858.

153. **Number and Designation of Comets.**—At present the number of comets known exceeds 700, but faint ones are continually being found by the telescope. Many doubtless exist whose nearest approach to the earth will lie outside any planetary orbit, so that they will never become visible even to our telescopes, and hence the total number must be very great. They are usually named after the astronomer who discovers them; but in some cases they are designated by the year of discovery, a Roman numeral indicating the order of their dis-

covery. Thus we have Encke's comet, Swift's comet, Donati's comet, &c. This last may also be given as Comet VI. 1858.

154. **Orbits of Comets.**—Some of the comets move in elliptical orbits, but of much greater eccentricity than the orbits of the planets, so that their ellipses are greatly elongated. In such cases they have a regular period of revolution, and are spoken of as *periodic comets*. Their elements can be determined, so that the time when they will approach sufficiently near to be visible can be safely predicted. Fig. 120 shows the orbit of Halley's comet. Its time of revolution is 76 years, and at its perihelion it is nearer the sun than the earth, while at aphelion it passes outside the orbit of Neptune. The comets whose orbits are ellipses are divided into two classes: *short-period comets* with periods less than 100 years, and *long-period comets* with periods estimated in thousands of years. Thus the comet seen in 1858 has a period of 2,100 years, and the comet of 1844 a period of 100,000 years. The following list supplies some data respecting the chief short-period comets. It will be noticed that in several cases the perihelion distances are less than that of the earth; in fact, nearly three-fourths of the total

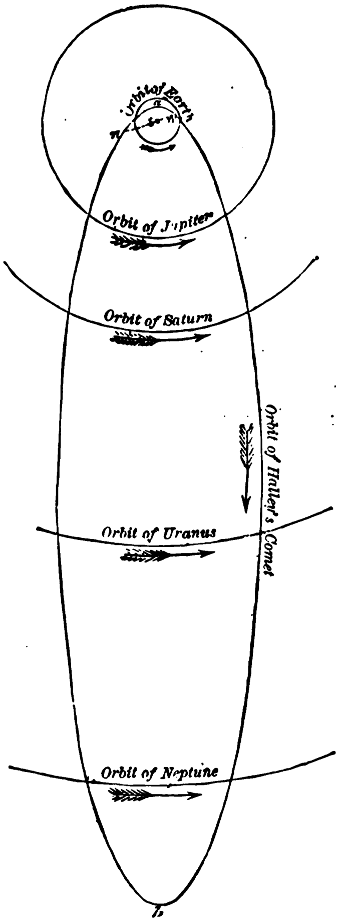


FIG. 120.

number of comets observed have their perihelion distance within the earth's orbit. In some instances comets have been observed that must have almost grazed the sun when nearest to that body.

Comet	Period	Perihelion distance	Aphelion distance	Next return
	Years			
Encke's .	3·29	32,000,000	381,000,000	1891, Oct.
Tempel's I. .	5·15	125,000,000	433,000,000	1894, Feb.
Winnecke's .	5·54	72,500,000	511,000,000	1891, Dec.
Brorsen's . .	5·58	57,500,000	526,000,000	1890, April
Swift's . . .	6·00	99,500,000	478,000,000	1892, Oct.
Tempel's I. .	5·98	164,000,000	448,000,000	1891, April
D'Arrest's .	6·64	109,000,000	532,000,000	1890, Sept.
Faye's . . .	7·44	157,000,000	550,000,000	1895, Dec.
Tuttle's . .	13·66	96,000,000	977,000,000	1899, March

But we now hasten to remark that a large number of comets do not move in closed curves like the ellipse, but in parabolic orbits, or orbits so nearly parabolic that the difference cannot be detected, and as the parabola is an open curve, and not closed like the ellipse, when they have passed round the sun they pass away into space, perhaps for ever—coming, we know not whence, returning, we know not whither. Further the orbits of comets differ from those of the planets in the fact that they are in planes inclined at all possible angles to the ecliptic, and their ascending nodes are found at all points of the same. As to the direction in which they move, some pass from west to east, and thus have a direct motion like the planets, but that of many others is retrograde. All the elliptical comets with periods of less than 100 years, except Halley's, are among those whose motion is direct. The relation of certain cometary orbits to that of some of the planets is also remarkable. Thus all the comets whose periods are less than eight years have orbits which bring them close to that of Jupiter at some point of their paths, and in cases where the orbit of the comet crosses that of Jupiter, one of the nodes is near the place of intersection, so that the planet and the comet might thus be brought close together, if they happened to be at this point of their orbits at the same time. The orbits of the seventy-five-year comets have a similar relation to that of Neptune. Such relations have led to the partition of many comets into families among the planets. Jupiter's family numbers sixteen, and includes all the short-period comets above mentioned. Neptune has a family of six, including Halley's; Saturn has two, and three are assigned to Uranus. Further, these relations have also led to a theory as to the origin of these comet families which regards the respective members of each family as having been specially influenced by those planets to which they now belong. For comets are not such old members of the solar system as the planets. They probably represent nebulous matter drawn into our system by the sun's attractive energy. As the solar system courses on through space it may meet a meteoric cloud patch and draw out the constituent meteors into a *parabolic swarm*. A comet coming into the solar

N 2

system from outer space, so that it is brought, in its parabolic orbit, near a planet, will have its motion either accelerated or retarded. In the first case its orbit would become a hyperbola, and when the comet had once passed the sun, it would never be seen again. But if its motion were retarded by the planet, its orbit would become elliptical, and the comet would acquire a regular period. Further diminution of velocity by the influence of the planet, and a further diminution of the size of its orbit to a certain limit, are also conceivable, and thus, with sufficient time and material to work upon, a family of comets, such as those which exist, might arise.

155. **Dimensions of Comets.**—The *head* or *coma* of comets has a diameter varying from 40,000 miles upwards. Donati's comet of 1858 had a diameter of 250,000 miles, while the head of the 1811 comet had at one time a diameter far exceeding that of the sun. It is a curious fact that the head contracts as the comet gets nearer the sun, notwithstanding the increased activity then set up by the sun, as is shown by the jets of vapour that rush forth from the coma. Probably the change is only optical, a part of the cometary matter becoming invisible. The diameter of the *nucleus* is sometimes as small as 100 miles, and sometimes as large as 8,000 miles. It undergoes changes which seem rather to depend on its activity at the particular time than on its distance from the sun. The tail in many comets is the most striking feature, for its size is often enormous. Projecting from the coma, and usually increasing in width the further it goes, its length is seldom less than 10,000,000 miles, and in many cases it has reached 100,000,000. The total bulk or volume of many comets with such trains will therefore exceed many thousand times the volume of the sun itself.

FIG. 121.—Donati's Comet on October 5, 1858.

156. **Mass and Density of Comets.**—But though the *volume* of comets may be so prodigious, the *mass* or weight is

always very small, even when we include the nucleus, which is the most closely packed portion. We are certain of this; because it has never been possible to detect any effect produced by a comet upon the earth or any other planet, although comets have often come so near a planetary body that their own orbits have suffered a complete change. Yet as the attraction of gravitation is always mutual, if they had contained but a very small fraction ($\frac{1}{100000}$) of the quantity of matter in the earth, appreciable effects would have occurred. But though the total mass cannot exceed the above fraction of a planet, it may be even many thousand times less, but we cannot say. The volume of a comet being so great and the mass so small, the *density* must necessarily be very minute. The quantity of matter in a cubic mile, for example, especially in the tail, must be small beyond all conception. This excessively small density is further confirmed by the fact that the small stars can be seen both through the head and tail of a comet with hardly any sensible diminution of their brightness. This excessively small mass and density does not compel us to conclude that the whole comet consists of extremely tenuous gas, as some have supposed; for it is more likely, as we shall presently see, that there are in it, or at any rate in the nucleus, numerous small, solid substances, widely separated, the inter-spaces only being filled with vapour.

157. **Changes undergone by a Comet.** – As a comet approaches the sun, rapid and extensive changes are often seen. 'Under the sun's influence luminous jets issue from the matter of the nucleus on the side exposed to the sun's heat. They are almost immediately arrested in their motion sunwards, and form a luminous cap: the matter of this cap then appears to stream out into the tail, as if by a violent wind setting against it.' This is explained by assuming a repulsive force of some kind acting between the sun and the matter emitted from the nucleus. Such a repulsive action would emanate from the sun if we suppose the sun's surface and the highly attenuated matter given off from the head of the comet to be in the same electrical condition, and this force, varying as the extent of surface, and not as the mass, would easily overpower the sun's attractive force on the extremely rare material expelled into a comet's tail. We may therefore regard the tail of a comet as formed of material driven off from the nucleus. Some of the larger comets when near the sun have their heads veined by jets of light passing from the nucleus, while others show a series of envelopes surrounding the nucleus, 'like hollow shells one within the other.' *Fig 122* gives a view of the head of the comet

of 1861, showing a number of luminous jets streaming out towards the sun and at a certain point arching round to form the envelopes just spoken of.

The matter thus repelled from the head of a comet, and again driven back by the repulsive action of the sun, goes to form the curved streamer of light known as the tail, the curve of the tail being always convex to the direction of the comet's motion. The tail is believed by some to consist of the repelled particles arranged into a hollow horn-shaped cone, but the exact form is thought to depend on the relative amount of the sun's repulsive action on the matter composing the tail. Bredichin, a Russian astronomer, has accordingly distinguished three types of tails:—(1) Long, almost straight tails, formed of matter on which the sun's repulsive action is very great, so that the particles leave the head at a great speed. These

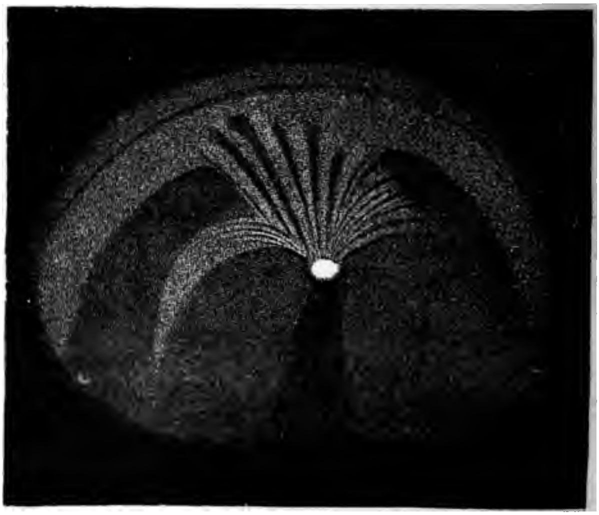


FIG. 122.—Head of the Comet of 1861, as observed by Secchi on June 30.

tails are believed to consist mainly of hydrogen. (2) Curved, plume-like tails, consisting of matter less forcibly repelled than in the first type. These tails are thought to consist of hydrocarbons mainly. (3) Short and sharply curved tails, formed of matter on which the repulsive force is but small. Such tails may consist of the vapours of sodium, iron, and other metals. Many comets exhibit tails of more than one type. A comet's tail is always directed from the sun, so that as the comet *approaches* the sun the tail seems to *follow* it, but as the comet *leaves* the sun the tail *precedes*, instead of following. This persistent position of the tail away from the sun is illustrated by fig. 123. Here the position of the sun on the ecliptic is marked on the lower line for September 27, October 8, and

ctober 14, and these places are connected by straight lines with the posi-
ns of the comet on these dates.

As far as we can see, each return of a comet to the sun must result in

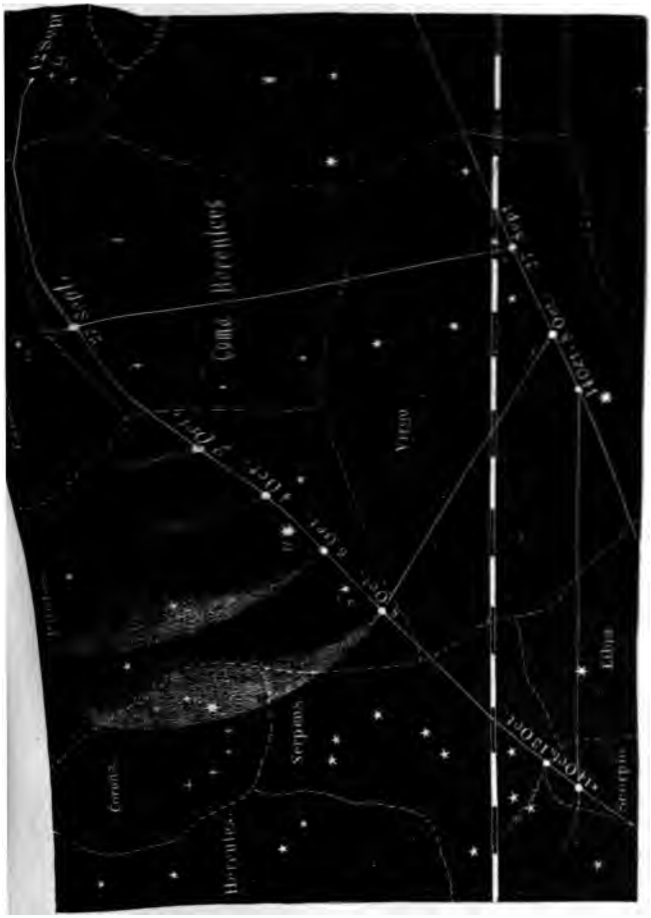


FIG. 123.—Orbit of Donati's Comet.

a loss of a portion of its substance; for it is then that the increased activity of the head reaches its greatest height and the tail its greatest length. The matter repelled represents a waste of the comet's material, for it cannot be recovered by the nucleus, but must pass off into space. There some

of the heavier vapours may condense, to again form small meteors, or the particles may be picked up by a planet as it passes through them. Many short-period comets have little or no tail, all the tail-forming material having apparently been previously set free.

158. **Structure of Comets.**—The most probable hypothesis regarding the nature of comets is that which regards the nucleus as consisting of a cloud of meteoric particles, most of the particles carrying with them an envelope of gaseous matter, often some form of carbon. How large these particles are it is impossible to say, but how sparsely scattered these particles must be is evident from what has been said about the extremely small density and the transparency of comets. As the comet gets near the sun, a tidal disturbance is set up in the swarm by solar attraction, the particles nearest the sun being most affected. The collisions between the particles thus increasing, the comet becomes hotter, and the meteoric vapours or dust-particles driven out of the head are repelled, to form the tail as already described. The light of the comet may be due in part to the heat generated by these collisions, and in part to electric discharges between the particles generated by solar influence. The powerful effect of a near approach to the sun has been observed on several occasions, notably in the case of Donati's comet, when the tail increased, between September 23 and October 10, from fifteen millions of miles to fifty-five millions of miles.

159. **Spectra of Comets.**—The light of a comet is in part reflected sunlight, and in part original, as is proved by spectroscopic examination. The inherent or original light is probably due to collisions among the meteoric particles and to electrical excitation combined. When examined in a suitable spectroscope a comet usually shows a faint continuous spectrum (the Fraunhofer lines being sometimes visible in this) over which are seen three bright bands, one in the yellow, one in the green, and one in the blue. These three *comet-bands* are attributed to hot carbon radiation, as an electric discharge through hydro-carbons, such as olefiant gas, seems to dissociate these compounds and give this same carbon-spectrum. It is also given when hydro-carbons burn in air or oxygen, the

blue flame of a Bunsen burner furnishing this spectrum perfectly.

Thus the carbon bands appear to point to the presence of

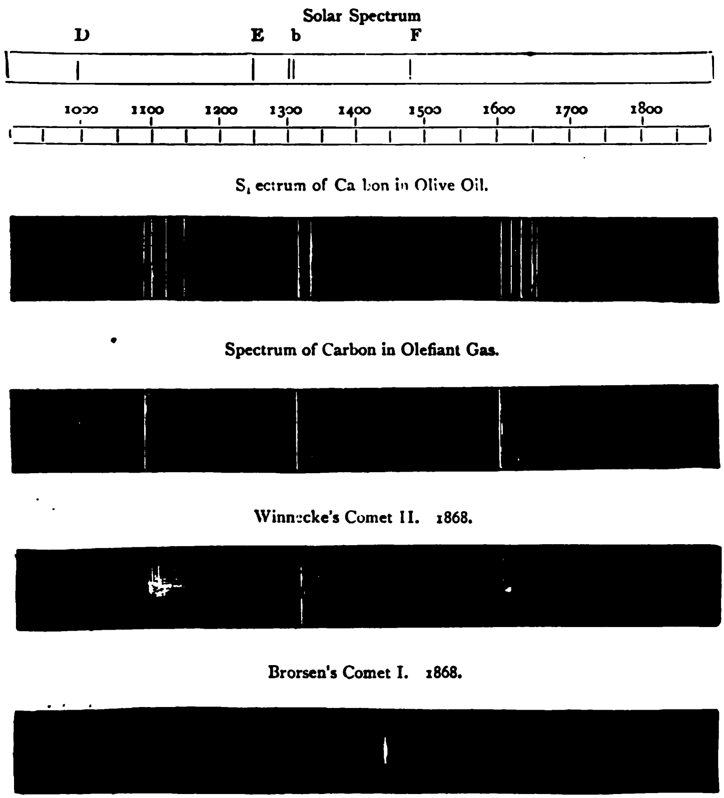


Fig. 124.—Spectra of Comets.

some form of carbon in comets. Professor Lockyer, in a paper read before the Royal Society, has pointed out that the spectrum above described is only one of the spectra furnished by a comet the particular spectrum furnished by any comet depending on its

proximity to the sun. Examined at a great distance from the sun, a line, or the edge of a bright fluting, is visible near λ 500; after this bands indicative of cool carbon appear; next appear the three hot carbon bands already mentioned; to these are now added light radiated from manganese and lead; signs of manganese and lead absorption now follow in the masking of the yellow carbon band; finally, at or near perihelion, in the cases of those comets coming very near the sun at this time, bright lines due to sodium and iron occasionally appear. This last was the case with the great comet of 1882, which approached at perihelion within half a million miles of the sun, while in the case of Winnecke's comet, which never got nearer than 70,000,000 miles, the heat produced by the sun's disturbance never became sufficiently great to bring out the bright iron lines. As the comet leaves the sun these variations in its spectra take place in reverse order. The sequence of phenomena thus observed, as a comet approaches or recedes from the sun, corresponds so closely with what is observed when meteorites are successively submitted to increasing temperatures, and the light examined by the spectroscope, that the meteoric view of the constitutions of comets is rendered almost certain. Both nucleus and tail being transparent, and the total mass being so very small, it is evident that the separate particles or meteorites constituting a comet must be widely separated from each other and cannot be very great, the whole thing consisting of a loose, transparent, revolving swarm, probably drawn or hurled into the solar system from interstellar space.

160. **Three remarkable Comets.**—Of the many remarkable comets whose appearance has been described, we have only space to speak of three. Halley's comet is of great interest, because it was the first whose period of revolution was estimated. From calculations made from observations of the comet of 1682, Halley found the orbit of this comet to be the same as that of great comets which had appeared in 1607 and 1531, and hence he concluded that these comets were really the same object, and that its periodic time was 75 years. The slight difference in *the intervals* he supposed were due to perturbations produced

by the planets Jupiter and Saturn. By computing the amount of these disturbances, a return of the comet in 1759 was predicted, and it actually passed its perihelion on March 12 of that year. Another return was predicted for 1835, and its perihelion passage occurred on November 16 of that year. Its next return will be in 1911. Encke first pointed out the periodicity of a small telescopic comet that bears his name in the year 1819. Its period of revolution is only about 3½ years, but this period diminishes about two and a half hours for each revolution, so that it is now more than two days less than when first estimated. As its periodic time is shortening, the size of its orbit must be getting less, for a short periodic time and a small orbit go together. But its velocity must increase, as can be proved by mathematics. This diminution in its periodic time, and in the extent of its orbit, has been referred to the resistance of an interplanetary medium, but the explanation is not entirely satisfactory. Biela's comet has a remarkable history, for, as a comet, it has passed out of existence. It was discovered by an Austrian named Biela, in 1826, and was shortly afterwards found to have a periodic time of 6½ years. It duly returned in 1832 and 1839, but at its next return, in 1845, it divided into two. The twin comets pursued the same path, and when next seen in 1852 were more than a million miles apart. Neither of these comets have ever appeared as comets since, although their orbit intersects that of the earth very near the point occupied by the latter at the end of September. But on November 27, 1872, as the earth was passing this point of the lost comet's path, a brilliant shower of meteors or falling stars was seen raining down at the rate of thousands in an hour. The same thing happened again in 1885, and on both these occasions the meteors appeared to radiate from a point in the constellation Andromeda, so that they are frequently called *Andromedes*. Now the *direction* from which these meteors come is the same as that from which Biela's comet comes, and the *times* at which they have been noticed are *times* when the return of Biela's comet was expected. We are therefore justified in regarding these meteors as the 'pulverised products' of the disintegration of

the vanished comet, and also in looking upon their orbits as the same as that of the lost comet. Besides Biela's comet, there are other comets which have, in all likelihood, divided into two or more distinct bodies, though they are not known to have afterwards been disintegrated into meteoric swarms. Thus there are groups of comets revolving in the same orbits and following one another at intervals, as if they had once been united.

161. **Meteors.**—The term *meteor* is now generally applied to certain sudden luminous phenomena, which, though occurring in the higher regions of the atmosphere, have an origin

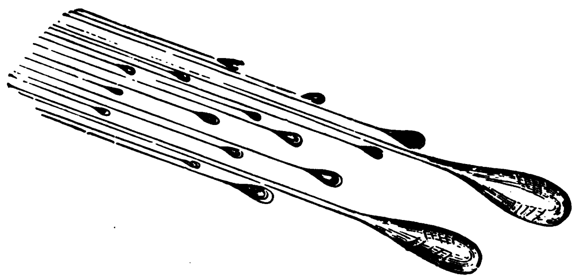


FIG. 125.—Balls of Fire seen through the Telescope.

external to our gaseous envelope. Meteors may be regarded as of three varieties: (1) *shooting or falling stars*, (2) *fireballs or bolides*, (3) *aerolites or meteorites*. *Shooting stars* are the commonest of meteoric phenomena. A point of light like a star suddenly appears and, rushing across the sky, leaves a trail of light that usually disappears in a second. The kind of meteor known as a *fire-ball*, or *bolide*, appears as a train of light rushing through the air, and at one part of its course bursting into fragments, with a loud noise often heard over a considerable area.

But the most remarkable and the rarest kind of meteor is one in which the flash of light and the loud detonation is followed by a body falling on the ground, the substance thus reaching the earth being called a *meteorite* or *uranolith* (heaven-stone). What has been learnt from the examina-

tion of such substances in the laboratory will presently be set forth.

None of these bodies are in any sense real *stars*, and the different kinds spoken of seem to have a like astronomical character, probably differing only in size, velocity, and constitution. The labours of astronomers have shown that they are of celestial origin, and consist of fragmentary masses revolving round the sun in orbits some of which cross the path of the earth. Should any strike our atmosphere, or be drawn into it by the earth's attraction, they are set on fire by the heat generated through the resistance offered to their passage by the air compressed in front of them owing to their rapid motion, and we then see them as streaks of light. These, however, form but a small fraction of a vast number circulating in all regions of space. We say a *vast number*, because if only one of these small dark bodies exist in 100 cubic miles of space, there would be countless millions within the planetary orbits. Of recent years much attention has been paid to these bodies, for they are found to play a much more important part in the universe than was at one time suspected.

162. **Identity of Cometary and Meteoric Orbits.**—The connection between comets and meteors, established by the effects observed through the disruption of Biela's Comet, has been found to hold in other cases. Though we may see a number of meteors or shooting-stars on any clear night, yet there are times at which special displays may be noticed. Such star-showers, as these extraordinary displays are called, are produced when the earth in its orbit encounters a stream of small bodies moving round the sun; for, when one of these bodies, moving with great velocity, strikes our atmosphere, also moving forward, with the earth in its orbit, at a velocity of over 60,000 miles an hour, it is made so hot by the friction that it burns, leaving a blazing streak across the sky till it is consumed. Four meteor-streams are well known, and their orbits have been found identical with those of four comets. The names of these streams, the date at which the earth crosses the orbit of each

stream, so as to produce the meteor-shower, and the comets with which each stream has been identified, are as follows:—

Name of shower	Date of appearance	Comet having identical orbit
Lyrids	April 19 to 20	Comet I. 1861
Perseids	August 9 to 11	Comet III. 1862
Leonids	November 12 to 14	Comet I. 1866
Andromedes or Bielas	November 27	Comet III. 1852

The case of the Andromedes has already been considered. The *great* November shower is that of the Leonids. An examination of old records shows that there has been a great autumnal display of meteors on November 13, at intervals of about 33 years, the last display occurring in 1866. Careful investigation has shown that this shower is due to a swarm of meteors revolving round the sun in an elliptical orbit which intersects the earth's orbit at the point through which the latter passes about November 13, the period of revolution being $33\frac{1}{4}$ years. If the meteors were scattered uniformly along the orbit, we should see an equal display every year on this date; but if they are mainly crowded along a certain part, the display will be greatest as the earth passes through the thickest portion of the swarm. Now the earth meets this thickest part of the swarm, at intervals of $33\frac{1}{4}$ years, on November 12, and accordingly, on this night, and on two or three nights on each side of this date, so broad is the swarm, a remarkable manifestation of shooting-stars is observed. Moreover, as the crowded part of the swarm is considerably extended along the orbit, it takes two or three years to pass the point of contact with the earth's orbit, and so the display is observed at this date for several succeeding years. Stragglers, too, appear to exist all along the path. The earth will next meet the main part of this great swarm in November, 1899, when another splendid display may be looked for. From the light given out by these bodies when they strike our atmosphere, a rough estimate of their sizes has been formed, and Professor Langley speaks of them 'as solid shot, of the average size of something like a cherry, or perhaps even of a cherry-stone, yet each an independent planetoid,

flying with a hundred times the speed of a rifle-bullet on its separate way as far out as the orbit of Uranus; coming back three times in a century to about the earth's distance from the

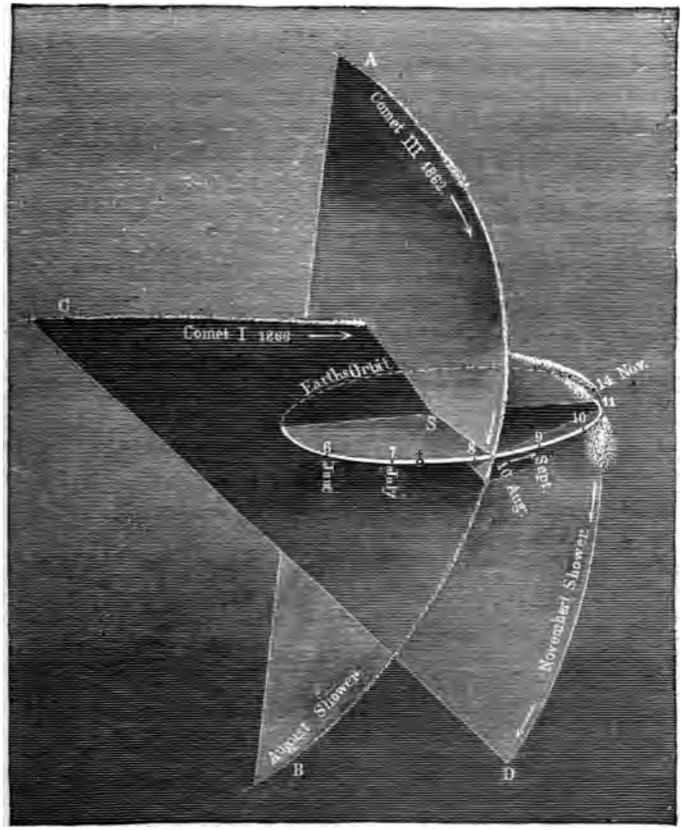


FIG. 126.—Part of the Orbits of the August and November Meteor Showers. (Orbits of Comets III., 1862, and I., 1866.)

sun, and repeating this march for ever, unless it happens to strike the atmosphere of the earth itself, when there comes a sudden flash of fire from the contact, and the distinct existence

of the little body, which may have lasted for hundreds of thousands of years, is ended in a second.'

When the elements of the orbit of these November meteors had been determined, it was soon found that a small comet discovered by Tempel (Comet I., 1866) was moving in the same orbit, an orbit with its perihelion point lying on the earth's orbit, its aphelion point beyond Uranus, and an inclination to the ecliptic of about 17°, and we have the important result established that 'The November meteoric showers arise from the earth encountering a swarm of particles following Tempel's comet in its orbit.' Fig. 126 shows a portion of the orbit of the November meteors, and how the earth's orbit comes in contact with the swarm, when it happens to be at the point where the two orbits cross. The date of the thickest shower undergoes a slight change as the point of intersection of the two orbits moves forward nearly 1·5° in a century, owing to a change in the position of the meteoric orbit. A similar connection has been established between the August meteors, known as the Perseids, and Comet III., 1862, so that the comet itself seems to be only a cluster of these meteors, the head being merely the denser part of the cluster. The August meteors often leave trails of luminous vapour lasting for several seconds, and, as they occur every year, we may infer that they are almost evenly distributed along their orbit. The Lyrids, or April meteors, are also known to move in the path of a comet.

163. **Radiant Point.**—When the paths described by the different members of a shower of meteors are traced backwards, they are found to intersect nearly in one point, which is called *the radiant.* Near this point the meteors appear without a train, because from there they are coming directly towards us. At a distance from the radiant, they have courses of more or less length. The radiant keeps its position among the stars while the shower lasts, partaking, of course, in the diurnal rotation of the celestial sphere. This apparent radiation from a point is simply an effect of perspective, for the meteors are really moving in almost parallel straight lines, and the trains of light they leave are also straight lines. No doubt the meteors are at

times deflected somewhat, owing to the friction of the air on their various forms. The radiant point of the Perseids is in the constellation Perseus, that of the Leonids in the constellation Leo, that of the Andromedes or Bielids, in the constellation Andromeda, and that of the Lyrids is near α Lyræ.

164. **Meteoric Swarms. Rings and Scattered Meteors.**—Many of the small bodies that give rise to the meteoric phenomena of the heavens, are collected into swarms or groups, and travel in elliptic orbits round the sun. As we have already seen, in some cases the meteoric orbit is the same as that of a comet. Other meteors seem to be spread through the whole of their orbit so as to form a ring. Where the group of meteors is close together, we only get a display if the earth happens to be passing through that part of the orbit which is intersected by the orbit of the meteors, and when the flock of meteors is at this meeting-place at the same time. This happens with the Leonids and the Andromedes, the great star-showers from these groups occurring at intervals of $33\frac{1}{4}$ and 13 years respectively. The Perseids seem to be more spread out all along the orbit, so that we have a smaller display from them every year, where the two orbits intersect. The last grand display of Leonids occurred on November 14, 1860, when more than 8,000 were counted at Greenwich in a single night. Moreover, there is a noticeable difference in the rate of movement during these star-showers, the Leonids moving swiftly as the earth meets them in its course, while the Andromedes move more slowly, as they simply overtake the earth. No doubt there are numerous other groups of meteors moving in elliptical or parabolic orbits, but not intersecting that of the earth, and therefore not rendered visible to us, as they are never ignited by being brought into friction with our atmosphere. But in addition to the well-known star-showers, there are other meteoric bodies which appear to be loosely scattered in space, or to proceed from orbits crossing the plane of the ecliptic in all possible directions, but not intersecting the earth's path, and which are not known to be associated with others from a radiant. These occasionally rush into our atmosphere singly, giving rise to striking effects, and in some cases they are so large

that the friction of the atmosphere is not able to effect their complete vaporisation, and they fall to the earth with a loud noise. At any rate, these scattered or *sporadic* meteors, as they may be called, are not known to form part of any group, and do not belong to any special part of the heavens. During the great star-showers of which we have been speaking, it is remarkable that no sound is ever heard, and *no masses ever reach the ground*, for these meteors first appear at an average elevation of about 75 miles, and, after passing in an oblique direction through 40 or 50 miles of the air, disappear at a height of about 50 miles. To this, there is only one exception known. On November 27, 1886, during the shower of Andromedes which occurred that evening, a piece of meteoric iron fell at Mazapil, in Mexico. But this difference between what comes to the earth during a star-shower, and what may be called sporadic meteors, does not necessarily indicate a difference of constitution. Most likely there is only a difference of size or mass. It has been estimated that the weight of the majority of meteors in a star-shower does not exceed a *grain*. But from the occasional meteors that have appeared, masses of stone or iron have sometimes reached the earth weighing more than a ton. The bodies that fall from the air to our planet, under such circumstances that they can be gathered up for examination, are called *meteorites*. To the results that have been learnt by examining meteorites, we will turn after a paragraph on the numbers of meteors generally.

165. **Number of Meteors.**—It is not unusual for a careful observer on a clear, moonless night to see eight or ten meteors in an hour, while Dr. Schmidt of Athens gives, as the result of his observations, the mean hourly number on such a night as 14. Such an observer does not, of course, take in the whole of his horizon at one time, and, making allowance for this, and for observers stationed over the whole earth, Professor Newton has calculated that 20,000,000 luminous meteors enter the atmosphere daily. Even this number of sporadic meteors would be increased many times by taking into account those only visible in a telescope. On the occasion of the showers alluded to *thousands* have been seen by one observer in a single hour.

All these figures point to the fact that space is by no means a mere void, but that it is permeated with these small bodies to such an extent that it has been estimated that 'in every portion of space equal to a cube whose edge is 210 miles, there is one meteoroid large enough to make a shooting star bright enough to be visible to the naked eye;' and that the average number in the space that the earth traverses is 30,000 in each volume equal to that of the earth. It is worthy of note that the number of luminous meteors seen in the six hours before midnight is little more than half the number seen in the six hours after midnight. This is explained when we consider that at 6 a.m. the observer's meridian is in the direction of the earth's orbital motion, while at 6 p.m. it is in the opposite direction. In the morning, therefore, we are on the forward half of the earth, as regards its motion in its orbit, while in the evening we are on the hind half, and assuming a planetary velocity somewhat exceeding that of the earth (a mean velocity of 26 miles a second has been estimated), it is plain that in the morning we see both the meteors that the earth *meets* and those that *overtake* it, but in the evening only those that *overtake* it. Remembering that meteors are always seen to shoot down and never upwards, and remembering their greater frequency after midnight and about the autumnal equinox in the northern hemisphere, as well as their enormous velocity, it becomes evident that these bodies cannot come from the earth, but must be of extra-terrestrial or cosmical origin. As to the number of meteors that reach the ground, only four or five are seen to fall on the average every year, but there must be a far larger number never seen and never found. One estimate places the number of these at 3,000 a year, the amount of matter thus added to the earth being calculated at 100 tons annually.

166. **Meteorites.**—Though still called a meteor in its flight through the air, the pieces which fall and reach the earth are called *meteorites*. A good collection of these objects may be seen in the Natural History Department of the British Museum at South Kensington, and a most useful 'Introduction to the Study of Meteorites' has been published by the Museum authorities. From this Introduction the reader may learn

some particulars about the *fall* of many of the chief meteorites. Reports of the fall of bodies through the air have reached us from very early times. In early ages these objects were regarded with great superstition and some of them received ceremonial worship. One of the oldest was a stone which fell in Phrygia and was taken to Rome in 204 B.C., its possession being deemed necessary to the welfare of the State. The Diana of the Ephesians was doubtless a meteorite. These are now lost, and the oldest stone from heaven that is still preserved is now suspended by a chain in the parish church of Ensisheim in Alsace. It fell there, accompanied by a loud and prolonged crash, on Nov. 16, 1492, and its weight before a part was broken off was 260 lbs. Passing over other records and coming to later times, we may mention the following falls: A fall of 3,000 stones over a region near L'Aigle in Normandy on April 26, 1803; a shower of 200 stones at Stannern in Bohemia in 1812; one large stone in Thuringia, Sept. 16, 1843; a large fall of stones in Hungary on June 9, 1866; a fragment of iron at Rowton, Shropshire, on April 20, 1876; a stone of 3 lbs. 8 oz. at Middlesborough, Yorkshire, on March 14, 1881.

Observations made on the luminous path of meteors at two or more stations many miles apart, have often been made to furnish a parallax from which the height of the meteor and the direction and length of its path have been found. The general result makes the meteor-paths commence at a height of 80 to 40 miles.

We learn that when meteorites enter the atmosphere a ball of fire appears to cross the sky and leave a trail of light, visible, if it appears in the day-time, at a distance of many miles, and if it appears at night it is often bright enough to light up the whole district. The fiery ball disappears in a few seconds with or without bursting into pieces, but usually accompanied by loud explosions and a prolonged roar. These noises are due in part to the disruption of the meteorite in its fall, and in part to the sudden rush of air into the vacuum left behind the swiftly rushing mass. Sometimes a single stone reaches the ground, sometimes several, and on rare occasions hundreds.

167. Classification of Meteorites.— M. Daubrée divides meteorites into four groups depending on their composition :

1. Those consisting entirely of metallic iron, or of iron alloyed with a small percentage of nickel, no stony mineral matter being present—*Holosiderites* (Gr. *holos*, whole, *sideros*, iron).

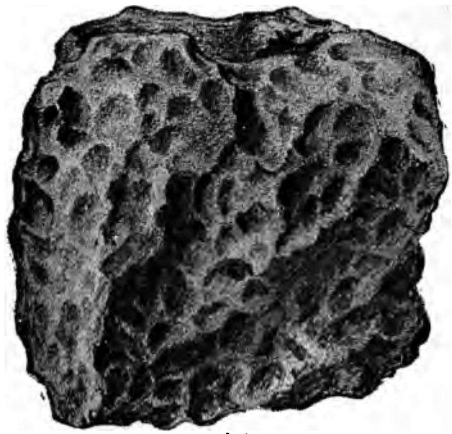
2. Those consisting of a nearly continuous mass of iron in which stony particles are disseminated—*Syssiderites*.

3. Those consisting of a mass of stony materials through which grains of metallic iron are scattered—*Sporadosiderites*.

4. Those consisting entirely of stony mineral matter, metallic iron being absent—*Asiderites*.

168. Physical Characters of Meteorites.—Their general character is that of irregular angular fragments, not unlike a piece of rock, or a piece of loose iron from a furnace. But the exterior and interior appearance are markedly different. The outside is covered entirely, or in part, with a very thin black crust, which may either be bright and glossy, or a dull black. This coating is the effect of fusion, and its thinness is due to the fact that the body coming from the cold of space conducts the heat, generated by the friction of the atmosphere, to the interior very slowly, whilst the air-molecules carry away the results of fusion almost as fast as the heat penetrates towards the interior. Some meteors also show results of fusion in fissures that interpenetrate their mass. The fused matter consists largely of oxide of iron and is strongly magnetic. This outer crust also often shows furrows and ridges, as well as peculiar depressions called 'thumb-marks' (see fig. 127). These depressions or pittings have been attributed to the 'inequality of conductivity and fusibility of the matter at the surface,' while the furrows and ridges are possibly due to the scooping action of the backward rush of air. When broken or cut through most meteorites are seen to be formed by an aggregation of granules or chondroi (Gr. *chondros*, a grain), causing them to exhibit a peculiar globular structure. The chondroi are sometimes firmly imbedded in a matrix, sometimes so loose that they fall out and leave a smooth spherical cavity (see fig. 128). They vary in size from a nut to a microscopic ball, and often form the

greater part of the stony meteorites. The minute chondroi are well seen in a thin section examined under the microscope. Reichenbach adds that each magnetic chondros 'is an independent crystallised individual—it is a stranger in the meteorite. Every chondros was once a complete, independent, though minute meteorite. It is imbedded like a shell in limestone.'



<......................19 centimètres......................>
FIG. 127—Pultusk (Poland) meteorite, showing thumb-marks or pittings.

169. Chemical composition of Meteorites.— No new *element* has been discovered in meteorites, but about one-third of the seventy known elements have been recognised. The elements most commonly met with in these bodies are iron, nickel, magnesium, cobalt, copper, manganese, silicon, carbon, hydrogen, oxygen, sulphur, sodium, potassium, nitrogen. Hydrogen, nitrogen, and carbon are the only elements that occur in the

<......................7·5 centimètres......................>
FIG. 128.—Muddoor (India) meteoric stone, showing chondritic structure.

free state, the carbon being found as graphite. The gases hydrogen and nitrogen, as well as some gaseous compounds of carbon (CO_2, CO, and CH_4), exist occluded in the substance of the meteorites and come out when the atmospheric pressure is removed. Many other compounds found in the terrestrial rocks exist also in meteorites, but the most abundant mineral of the earth's crust—quartz, SiO_2—is entirely absent. The chief mineral compounds common to meteorites and terrestrial minerals are *olivine* $(MgOFeO)_2SiO_2$, a silicate of iron and magnesium; *enstatite*, $MgSiO_3$; *bronzite*, a variety of enstatite containing iron; *augite*, a silicate containing lime, magnesia, alumina, and the protoxides of iron and manganese; and *magnetite*, Fe_3O_4. There are, however, several mineral *compounds* found in meteorites that are never found in the rocks of the earth. Among these are *troilite*, a compound of iron and sulphur (FeS); *oldhamite*, a compound of calcium and sulphur; *schreibersite*, iron and nickel phosphide with magnesium; and *daubréelite*, a compound of iron, chromium, and sulphur. In the so-called 'iron' meteorites the chief substance is an alloy called *nickel-iron*, and in its mode of occurrence it is special to these bodies.

<················8 centimètres·················>

FIG. 129.—Linn County (Iowa, U.S.A.) meteorite, showing granules of iron dispersed in stone. The fissures contain dark matter like the crust.

<············5·2 centimètres············>

FIG. 130.—Meteoric iron (Seneca River, U.S.A.), showing Widmanstätten markings.

170. **Holosiderites.**—Holosiderites, or simply siderites, usually consist of from 80 to 95 per cent. of iron, and from 5 to 10 per cent. of nickel. The nickel always forms an alloy with the iron, and its presence often gives the fractured surface of meteoric iron a bright, silver-like appearance. Manganese and cobalt are also found in the siderites, while schreibersite and troilite are frequent constituents. The gases hydrogen, nitrogen, marsh gases, and the oxides of carbon occur occluded in many iron meteorites, and come out when they are placed in a vacuum. When the bright polished surface of meteoric iron is acted upon by an acid, a portion of the surface is dissolved, while other parts are left in relief, in lines lying along the two faces of a regular octahedron. These complicated but regular crystalline markings on the face of a meteoric iron are known as 'Widmanstätten figures.' (See fig. 130.) Only ten iron meteors have actually been seen to fall, the largest of these, weighing about 130 lbs., reaching the earth at Nejed in Arabia in 1863, and another, nearly 7 lbs., falling at Rowton in Shropshire in 1876. But many other larger specimens of meteoric iron are in our museums, having been found under such circumstances that they cannot be accounted for except by regarding them as meteorites. Thus an iron mass, weighing 5 tons, found near Bahia in Brazil and now at Rio Janeiro, is an undoubted meteorite. In some cases, however, masses of iron alloyed with nickel have been supposed to be of meteoric origin when the rocks of the neighbourhood have been shown to contain nickeliferous iron. It is owing to this consideration that the large masses known as Ovifak iron, and brought from Western Greenland, are now generally considered to be of terrestrial origin.

171. **Syssiderites.**—The second group calls for little special notice. The nickeliferous iron in these amounts to only about 12 per cent., but the iron is also found in combination with the minerals magnetic pyrites, chrome-iron, and olivine. Hornblende, which is closely allied to augite, also occurs.

172. **Sporadosiderites.**—This is the commonest variety of meteorite (in the proportion of 10 to 1), and they are often spoken of simply as aërolites, or air-stones. These stony meteorites, when examined in thin sections under the microscope, are seen to be almost entirely crystalline in structure, and in most cases they show the peculiar chondritic structure already alluded to. The chondroi, or grains, are of various sizes, and are imbedded in a paste or matrix of the same mineral ingredients. It is believed by Sorby that the small spherules of which the chondroi consist have fallen as drops of fiery rain, while the internal crystalline structure of the chondroi differs from anything found in terrestrial rocks. Many stony meteorites not only present a fragmentary appearance as a whole, but the internal structure is fragmentary, like a piece of brecciated rock. The largest aërolite, or stony meteor, known to fall, came down in 1866. It weighs 647 lbs., and is preserved in the Vienna Museum. The chief minerals found in the stony meteorites are olivine, enstatite ($MgSiO_3$), bronzite (enstatite with a little iron), chromite, augite, and anorthrite.

173. **Asiderites.**—The last group of meteorites contains no metallic iron, though it may exist in combination. Many of its members contain carbonaceous matter, the carbon existing in combination with hydrogen and oxygen. (Elemental carbon, as graphite, is found in some iron meteors.) Soluble sulphates of magnesium, sodium, and potassium also occur, whilst magnetite is occasionally found in microscopic crystals. The presence of compounds of carbon, such as result from vegetable decomposition, is curious,

but no trace of life or of any organism has ever been seen. A remarkable carbonaceous meteorite fell at Mighei in Russia, on June 9, 1889.

174. **Meteorites compared with Terrestrial Rocks.**—Professor Judd points out in his work on volcanoes the remarkable fact that the mineral constituents of many meteorites are such as are found in the more basic volcanic rocks, like basalt and gabbro ('El. Phys.' par. 142). In these basic rocks quartz and the acid felspars are entirely absent, so that the percentage of silica is small. Such ultra-basic rocks are the products of deep-seated lava, have a specific gravity of a little over 3, which is also the average for the stony meteorites, and are almost entirely composed of the minerals most abundant in meteorites; viz., olivine, enstatite, augite, magnetite, and chromite. 'We thus see that materials identical in composition and character with the stony meteorites, exist within the earth's interior, and are thrown out on its surface by volcanic action.'—Judd. But we must bear in mind that there are mineral compounds peculiar to meteorites, as well as peculiarities of crystalline and chondritic structure, not found in terrestrial minerals. The idea, therefore, that meteorites are the product of terrestrial or lunar volcanoes can hardly be entertained. It is more probable that they are of cometic origin; for we know that comets—possibly patches of meteoric nebulæ drawn into the solar system—do break up, and that the meteorites of which they consist have been subject to the action of heat and other violent forces at successive perihelion passages. Hasty crystallisation of vapours in the cold of space, and subsequent heating, clashing, and cementing of particles, may account for many of the observed peculiarities in the mineral structure of meteorites. Other authorities believe that meteorites are fragments of asteroids driven into orbits which occasionally bring them within the range of the earth's attraction.

175. **Spectrum analysis applied to meteorites.**—When a portion of meteoric dust or filings is gently heated in a vacuum-tube through which an electric current is made to pass, the spectroscope always renders the hydrogen spectrum visible first. As the temperature is increased, the spectrum of carbon, or one of its compounds, begins to appear; at a still higher temperature the magnesium spectrum is seen. This last element is a constituent of the mineral olivine, the chief substance of the stony meteorites. Magnesium is also found as a constituent of the iron meteors in schreibersite, a non-terrestrial mineral formed mainly of the phosphides of iron and nickel. At the temperature of the oxy-hydrogen flame the spectra of manganese and then iron come out. By employing the temperature of the electric arc, and using the meteorites themselves as the poles, the complete spectra of both iron and stony meteorites have been photographed. As before remarked, a mixture of meteorites in the electric arc gives a spectrum of bright lines matching many of the dark lines of the solar spectrum. It may be observed that the substance which becomes a vapour at the lowest temperature is the one whose spectrum first appears in these experiments in whatever proportion it exists in the meteor that is being examined, the order of appearance of the various spectra depending upon the relative volatility of the various substances and not upon relative quantity.

176. **Cosmic Dust.**—It is an interesting inquiry to seek to know what becomes of the products of combustion of those meteors that are consumed in passing through the air. As their combustion is merely a chemical combination with the oxygen of the air, the products of this combustion must exist somewhere as gas or fine dust. The word cosmic (Gr. *kosmos*, universe) is used in contrast to the word terrestrial or telluric (Lat. *terra*

and *tellus*, the earth). Hence when we speak of something having a cosmic origin, we imply that it has come from some other source than our planet. Now the tiny meteors that produce such striking luminous effects are certainly visitors from space and foreign to the earth, so that the meteoric dust that results from their combustion is of cosmic origin. The spectroscopic examination of shooting stars and fireballs has given distinct evidence of magnesium and iron, the two chief elements found in stony and iron meteorites. The sodium line has also been seen. Other considerations point to the conclusion that has already been referred to, viz., that luminous meteors and meteorites are of similar chemical constitution. We can therefore see that the products of the incandescent particles of iron, nickel, the various silicates of magnesium, &c., will consist largely of other solid particles, among which magnetic oxide of iron will be prominent; for, on burning a strip of iron in a jar of oxygen, the fused metal falls in spherical drops surrounded by a coating of the black oxide. Most of this meteoric dust will be very fine, and will therefore remain suspended in the higher parts of the air, where the smaller meteors are mainly consumed, but part of it will fall on the surface of the globe. The dust that remains in the air is believed to manifest its presence in the spectrum of the *aurora*, a phenomenon described in 'El. Phys.' par. 289. Now it is evident that some of this cosmic dust will fall to the earth. But it is extremely difficult to be sure that any found is of meteoric origin. It is useless to look for it in inhabited countries where iron foundries exist, or in the neighbourhood of volcanoes. The Swedish naturalist Nordenskiold, on melting several tons of arctic snow, and filtering the water, found minute globules of oxide of iron, which he believed to be of cosmic origin. From the deeper oceanic deposits of the Atlantic and Pacific minute black spherules of native iron, with a black shining coat of magnetic iron, as well as others consisting of an alloy of iron with nickel and cobalt, have been extracted. Small grains (chondroi), somewhat larger than the two kinds of spherules above described, are also drawn by a magnet from the red clay of the deep sea. These are not quite round, and consist of bronzite and such silicate granules as do not occur in terrestrial rocks. Both the spherules and the chondroi are believed to be derived from meteoric dust. This may be so; but, in view of what has been learnt, from the volcanic explosion at Krakatoa ('El. Phys.' 160), about the enormous distance to which volcanic dust may be carried by winds, a terrestrial origin for some of these particles is not altogether out of question.

CHAPTER X.

THE MOTIONS OF THE EARTH—CHANGES IN THE ORBIT.

177. In the concluding chapter of our 'Elementary Physiography' we have given an account of the daily rotation of the earth on its axis and of its annual revolution round the sun. We have there established the following truths :—

Rotation causes the risings and settings and daily apparent motions of the sun and stars, and thus causes day and night.

Revolution causes the sun to appear to move eastward amongst the stars, and thus stars rise earlier on successive nights.

Revolution and the inclination of the planes of the equator and ecliptic cause the difference in length of the days and nights, the difference in height of the midday sun, and thus cause the succession of the seasons.

Rotation gives us the length of the day; *revolution* the length of the year.

The earth's movement of rotation is known to be uniform, and the interval in which it is performed may be regarded as invariable. The time of such rotation can be ascertained by noting when a particular fixed star is exactly south—that is, when it culminates on the meridian of the place of observation, and then noting when the same star again reappears on the meridian. The time between the two meridian passages of the same star is always of the same length, and is frequently called a sidereal day. A meridian of the earth has in this time turned through exactly 360°. It might, therefore, be thought that the length of the interval in which the earth makes a complete revolution on its axis would be the best unit of time, as it is the most simple.

But the passage of a star across the meridian is not a sufficiently conspicuous event for the ordinary purposes of life. These are regulated by the sun, and hence the ordinary day is measured by the interval between two meridian passages of the centre of the sun. Now this interval is nearly four minutes longer—more exactly, 3 m. 56 s.—than the time of the earth's rotation, or the sidereal day. The greater length of the solar day is owing to the fact that when the earth has made a complete turn, so as to bring the meridian of a place to the same distant fixed star that was on the meridian at noon on the previous day, the sun has apparently moved eastward among the fixed stars nearly one degree. The earth, therefore, takes about four minutes more to move on through this degree, so as to bring the sun again on the meridian of the place of observation. Fig. 131 illustrates this clearly. E_1 and E_2 represent two positions of the earth in its orbit at an interval of a solar day. Let M represent the position of the sun, and let P A be the meridian of a place. At E_1 suppose the sun and a distant fixed star are on the meridian at the same time; then at E_2, when the distant fixed star is again on the meridian at A, the meridian having turned through 360°, we see the sun has not come up to the meridian, and the earth must continue to turn till it moves through the further arc A B. If this eastward motion of the sun among the fixed stars were uniform, the length of the solar day would be as simple and as easily found as the length

of the sidereal day. But it is not uniform, and hence solar days are unequal and fluctuating, being greatest when the sun is nearest the earth and least when most distant. The apparent time, as shown by the true sun, is indicated by a sun-dial; but it would be impossible to construct a clock to keep apparent solar-time, as its rate would have to change from day to day in a complicated way. To avoid the inconvenience arising from this inequality in the length of the solar day, we have recourse to a mean or average solar day. The various kinds of day are thus set forth in the explanations at the end of the 'Nautical Almanac.'

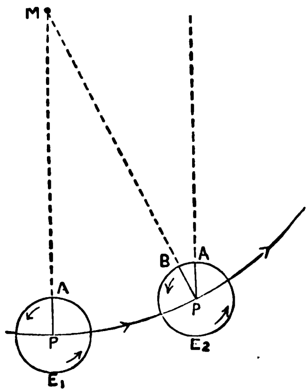


FIG. 131.

'A *day* is the interval of time between the departure of any meridian from a heavenly body and its succeeding return to it, and derives its name from the body with which the motion of the meridian is compared. The interval between the departure and return of a meridian to the sun is called a *solar* day; in the case of the moon, the interval is called a *lunar* day; and in that of a star a *sidereal* day. The revolution of the earth on its axis is always performed in the same time; and if the heavenly bodies preserved the same positions with respect to each other, the intervals between the departure and return of a meridian to each would be the same, and all days, consequently, of equal length. The sun (or, more strictly, the earth in its orbit), the moon, and the planets are, however, in continual motion, and with velocities not only different from each other, but varying in each particular body; the length of a day, as determined by any of these bodies is therefore a variable quantity.

'Astronomers, with a view of obtaining a convenient and uniform measure of time, have recourse to a *mean solar day*, the length of which is equal to the mean or average of all the apparent solar days in a year. An imaginary sun, called the *mean* sun, is conceived to move uniformly in the equator with the real sun's *mean* motion in right ascension, and the interval between the departure of any meridian from the *mean*-sun and its succeeding return to it, is the duration of the *mean solar day*. Clocks and chronometers are adjusted to mean solar time; so that a complete revolution (through twenty-four hours) of the hour-hand of one of these machines should be performed in exactly the same interval as the revolution of the earth on its axis with respect to the mean sun. If the mean sun could be observed on the meridian at the instant that the clock indicated 0h. 0m. 0s., it would again be observed there when the hour-hand returned to the same position. As the time deduced from observation of the true sun is called *true* or *apparent* time, so the time deduced from the *mean* sun, or indicated by the machines which represent its motion, is denominated *mean* time.

'Mean time cannot be obtained from observation; but it may be readily deduced from an observation of the true sun, with the aid of the equation of time, which is the angular distance in time between the mean and the

true sun. Suppose the true sun to be observed on the meridian of Greenwich, January 1, 1890; it would then be apparent noon at that meridian; the equation of time at this instant is 3 m. 53·88 s., and, by the precept at the head of the column, it is "*to be added to apparent time*"; hence, it appears that the corresponding mean time is Jan. 1, 0 h. 3 m. 53·88 s., or that the mean sun had passed the meridian previously to the true sun, and that at the instant of observation the mean-time clock ought to indicate this time.'

178. **Equation of Time.**—We shall now explain this term in more detail. The equation of time is the amount by which the sun is fast or slow, as shown by a clock; that is, it is the length of time to be added (algebraically) to the true solar time, so as to get the mean solar time. True solar time is given by the sun-dial, mean solar time by a clock, so that

$$\text{Dial Time} + \text{Equation of Time} = \text{Clock Time.}$$

Sometimes the dial indicates noon after the clock does; then the equation of time is *positive*. At other times the dial indicates noon before the clock, and then the equation of time is *negative*.

The Equation of Time is therefore the difference between apparent or sun-dial time and mean time as shown by the clock, and serves for the conversion of either time into the other. In the 'Nautical Almanac' we find the equation of time to be added to, or subtracted from (according to the direction given), Greenwich apparent noon to obtain the corresponding mean time for every day in the year. Apparent time is usually obtained by observations of the meridian passage of the true sun.

The mean sun, which is to give us our mean time, is to move uniformly along the equator, whilst the true sun, which gives us true solar tlme, is moving at an unequal pace along the ecliptic. So the equation of time will be made up of two parts.

(1) One due to the unequal motion of the sun in the ecliptic produced by the real unequal motion of the earth in its orbit, which moves faster when nearer to the sun, the daily motion ranging from 61′ to 57′.

(2) Another due to the inclination of the ecliptic to the equator, which causes the sun's motion in the ecliptic to be more oblique to the equator at the equinoxes than at other times.

These two parts of the equation can be considered separately, though it is their conjoint effect which determines the value of the equation. So far as the unequal motion in the ecliptic is concerned, this part of the equation will be zero at perihelion and aphelion, the two extremes of the path at which the *true and mean sun* would coincide if their orbits were in the same

plane. This first part of the equation is positive from perihelion at January 1 to aphelion on July 1; and negative from July 1 to January 1, being equal to zero on these two dates. The maximum values are midway between these two dates, i.e., about April 1 and October 3, and then reach + 8 minutes and − 8 minutes.

As far as the obliquity is concerned, the effects are different. The critical dates are the two equinoxes and the two solstices. At all four of these the second part of the equation is zero, and it changes its sign four times in the year. From solstice to equinox it is +, and from equinox to solstice it is negative.

Therefore from December 22 to March 21 it is +
from March 21 to June 22 it is −
from June 22 to September 23 it is +
from September 23 to December 22 it is −

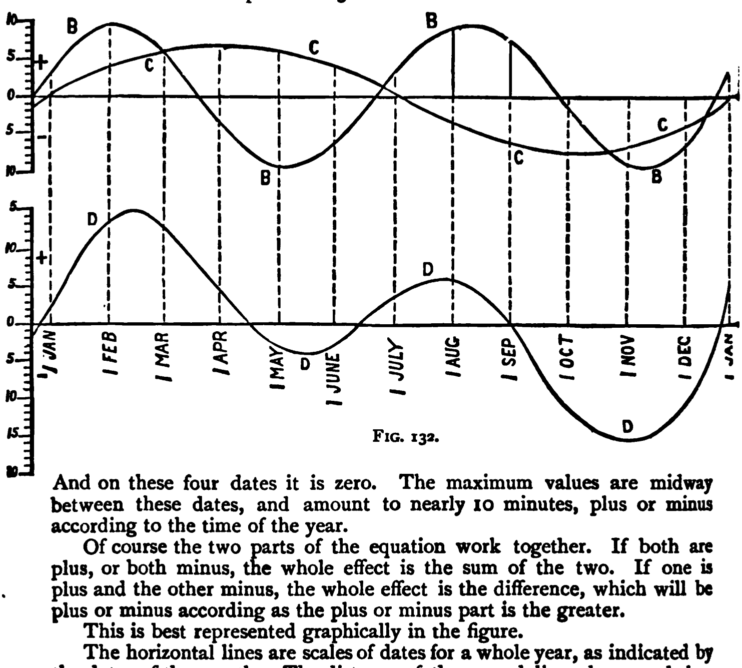


FIG. 132.

And on these four dates it is zero. The maximum values are midway between these dates, and amount to nearly 10 minutes, plus or minus according to the time of the year.

Of course the two parts of the equation work together. If both are plus, or both minus, the whole effect is the sum of the two. If one is plus and the other minus, the whole effect is the difference, which will be plus or minus according as the plus or minus part is the greater.

This is best represented graphically in the figure.

The horizontal lines are scales of dates for a whole year, as indicated by the dates of the month. The distance of the curved line above or below the horizontal for any particular day, represents the amount and sign of the equation for that date as given by the vertical scale of minutes at the side.

The line C C C C represents the part of the equation due to the unequal velocity, which crosses the horizontal for zero value twice in the year. The line B B B B similarly represents the part due to the obliquity of the ecliptic, which is zero four times in the year. The line D D D D, in the lower half of ...resents the true equation of time, which is the combined effect

of the other two. It is obtained by taking each date, and adding or subtracting, as the case may be, the vertical distances of the points on B B B B and C C C C corresponding to each date. Fig. 132 shows that the equation of time is zero on four days in each year, viz. on April 15, June 14, September 1, and December 24.

The maximum values occur at the bends of the curve, and are

+ 14 mins. 32 secs. on February 11;
– 3 mins. 5 secs. on May 14;
+ 6 mins 12 secs. on July 26;
– 16 mins. 18 secs. on November 2.

The values for other dates may be obtained approximately from the figure, but are given with accuracy in the tables of the 'Nautical Almanac.

179. **Secular Changes in the Orbit of the Earth.**—The earth's orbit is not absolutely unchangeable in form and position. This could only be the case if the earth were the only planet revolving round the sun. The gravitational attractions of the other planets, also revolving round the sun, cause certain small changes in this orbit; and as the round of these changes is spread over very long periods, such changes are called *secular* changes (Lat. *sæculum*, an age or generation). These secular changes are three in number.

1. *A change in the position of the orbit, or a change in the obliquity of the ecliptic.*—The angle of inclination between the ecliptic and the equator is known as the *obliquity of the ecliptic.* It is equal to the sun's greatest declination or greatest distance from the equator. This greatest declination is reached in June and December, at two points midway between the equinoxes. These two points are known as the *solstices*, because the sun appears to *stand*, or stop its motion of declination for a short time, and the two circles through these points are called the *tropics*, because the sun there *turns* towards the equator again. At present the plane of the ecliptic is inclined to the plane of the equator at an angle of about 23½. But this angle is less by about 24′ than it was 2,000 years ago, and is still decreasing. Its least value will be about 22¼°, when it will again increase. The total change is only about 1° 2′ on each side of the mean value.

2. *A change in the eccentricity of the orbit.*—The eccentricity is the distance from the centre of the orbit to the focus divided by the semi-major axis. This ratio, now about ·0168, is slowly diminishing, and will in about 24,000 years reach a value of ·003. After this time the eccentricity will again increase.

3. *Revolution of the line of apsides of the earth's orbit.*—The line joining perihelion and aphelion is slowly and steadily moving eastward at a rate of nearly 12″ annually. This will carry it completely round in about 108,000 years. Since the vernal equinox from which longitude is reckoned is moving in an opposite direction at a rate of about 50″ annually, the longitude of perihelion must change at a yearly rate of about 62″. Hence though the line of apsides completes a sidereal revolution in 108,000 years, it will pass from equinox to the same equinox, or through a cycle of the seasons, in about 21,000 years. On the climatic effects in each hemisphere resulting from the sun being in perihelion at different seasons, something will be said later.

The periods of all these secular changes are some thousands of years. There are two constants in connection with the earth's orbit which are unaffected by perturbations. These are the length of the major axis and the length of the year. It is of interest to note that Lagrange and Laplace have proved that the mutual perturbations of the planets can never destroy the solar system.

180. **Precession of the Equinoxes.**—Besides the above perturbation of the earth's orbit, there are changes in the direction of the earth's *axis*, which are referred to under the names of *precession* and *nutation*. Precession was first discovered by Hipparchus, 120 B.C., on observing the difference in the length of the year as measured by two methods: (1) from one equinox to the same equinox next year, or from solstice to the same solstice next year by the shadow of a stick or gnomon; (2) by observing the position of the sun with reference to the fixed stars, and measuring the year from one position back to the same position. The first measurement gives us the length of the *equinoctial* or *tropical* year, and the second measurement the length of the *sidereal* year. The former interval gives a length 20 m. 23 s. less than the latter interval. The difference is due to a gradual shifting of the plane of the equator, which causes the points of intersection of the equator and the ecliptic to move backward so as to meet the sun sooner in its eastward motion along the ecliptic. Hence each succeeding vernal equinox will happen a little earlier than it otherwise would, and this advance of the equinoxes is called their precession (in time) because it makes them precede their sidereal time. That the first point of Aries does move backwards is proved by the fact that the longitudes of the stars as measured from this point, show an increase at the mean rate of $50''{\cdot}2$ per annum, while their latitudes are very nearly constant. This, again, leads to the inference that the plane of the equator has a retrograde motion along the ecliptic, while the plane of the ecliptic is very nearly a fixed plane. But if the equator moves, its poles must move, and, in fact, the pole of the equator slowly swings round the pole of the ecliptic. In other words, the earth's axis, which was regarded, in describing the seasons, as always pointing in the same direction, and as always remaining parallel to itself, does not, strictly speaking, keep a

fixed position, but suffers a slight change of direction during each yearly revolution.

The motion of the celestial pole round the pole of the ecliptic, and the consequent shifting of the equinoctial points, is illustrated in fig. 133. Let A B C D denote the plane of the ecliptic and E that of the celestial equator. Then K is the pole of the ecliptic and P the pole of the equator in the position E A E. As the plane of the equator glides backwards to the successive positions E′ A′ E′, E″ A″ E″, the pole of the equator moves to the position P′ and P″ respectively, the obliquity of the ecliptic being unaltered. Neglecting a small planetary perturbation, the plane of the ecliptic is immovable, and there is a constant distance between the two poles of $23\frac{1}{2}°$, the same as the angle between the planes of the equator and the ecliptic. This revolution of the pole of the equator round the pole of the ecliptic causes the backward motion of the equinoctial points, illustrated in the figure by the positions A, A′, A″ of the first point of Aries. It is, in fact, the same thing as the precession of the equinoxes; for if we suppose the earth moving from A along the plane of the ecliptic, it is plain that it will reach the point A′ to which Aries has moved in consequence of the shifting of the equatorial plane, before it has completed a sidereal revolution. The effect of precession on the position of a star is also illustrated in the figure. Let *e* be the position of a star, and *eb* the perpendicular arc drawn to the fixed plane of the ecliptic. Then the angular distance of *b* from the first point of Aries is the longitude of the star. This is measured by the arc A *b* in the first position of Aries, by the arc A′ *b* next year, and so on. It is thus evident that the increase in the longitude of stars is due to precession. The latitude as measured by the arc *e b* is not altered. As the time of equinox advances 50″·2 per year, owing to the backward motion of the first point of Aries, the period of precession, or the time required for a complete revolution of this point, will be nearly 25,800 years (360° divided by 50″·2).

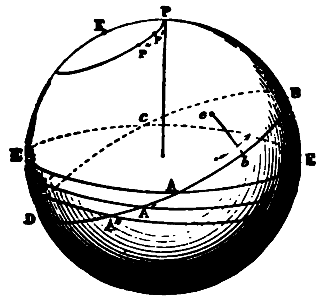


FIG. 133.

If we refer the position of the star *e* to the equator as the fundamental plane, it will be clear that the right ascensions and declinations of stars will suffer variations from precession.

Another effect of precession is the gradual shifting of the constellations with respect to the equinoctial points. About 120 B.C., the first point of Aries was in the constellation whose name it bears, but since that time it has shifted through nearly 30° and is now in the constellation Pisces, and in the course of time will pass through other constellations. A change of pole star is also an effect of precession. The pole of the ecliptic is a fixed point in the constellation *Draco*, and the path traced out by the pole of the equator is a circle of angular radius $23\frac{1}{2}°$ round this point as centre. At any particular period the earth's axis will be directed, and will continue for some time to be very nearly directed, to some one point on this circle. The star at or near that point will be the pole star for that period, every star on

the circle having its turn in the course of 25,800 years. At present our pole star is about $1^\circ\frac{1}{4}$ from the true pole. When the true pole has approached within 30′ of Polaris, it will then recede, and at the end of 12,000 years the pole will be near the bright star Vega (α Lyræ), which at present is nearly 46° from the pole.

181. **Physical Cause of Precession.**—If the earth were a homogeneous sphere, there would be no precession. The cause of precession is the attraction of the sun and moon on the equatorial portions of the earth which bulge out above the true sphere, tending to pull the plane of the equator into the plane of the ecliptic by attracting more strongly those portions of that bulging part which are nearest to them. The combined effect of this tendency to draw the axis of the earth into perpendicularity with the plane of the ecliptic, and of a spinning round this axis, is to make the end of the earth's axis turn in a circle round the axis of the ecliptic. It is like the case of a spinning-top : its weight tends to pull the axis over to a horizontal position ; this tendency, combined with the spinning, causes the axis to describe the surface of a cone round the vertical line. Precession in the case of the earth is slow, because of the enormous energy of its spin, and the comparatively feeble force which acts on the small mass which bulges out above the rest of the earth. The effect thus produced by the action of the sun is known as *solar precession*, that produced by the moon *lunar precession*, and the combined effects of these two bodies is called the *luni-solar* precession. As the precessional effect of the sun and moon is due to the *difference* of attraction on the near and far parts of the earth's equatorial protuberance, the moon's share of the total effect is greater than that of the sun, its much closer proximity more than counterbalancing the sun's much greater mass. The moon's action in causing precession, as in producing the tides, is, in fact, about two and a half times that of the sun, though the sun's attraction on the earth as a whole is nearly 200 times that of the moon. The precessional effect of the sun's attraction is greatest at the solstices. At the winter solstice the nearer half of the equatorial protuberance is above the ecliptic, and the further half below it ; *vice versâ* at the summer solstice. At the equinoxes the sun has no precessional effect. The lunar

part of the precession also varies according to the position of the moon in its orbit. The amount of precession previously given, 50″·2, is the average or mean precession in a year.

182. **Nutation.**—The pole of the equator does not trace out a circle exactly, but a wavy curve, partly within and partly outside the circle. The axis does not steadily sweep round, but in its circuit 'nods' in and out a little; hence the name *nutation* (Lat. *nuto*, to nod). The curve then traced out by the pole is as in the figure, except that there should be 1,400 indentations in the circumference, which is traversed in 25,800 years. The causes of nutation are the same as those of precession; or rather nutation is an irregularity in those forces which produce precession. When the precessional forces increase, they cause the earth's axis to 'nod' within the circle and when they decrease it 'nods' to the outside of the circle. There are two kinds of nutation: (1) *Lunar nutation*, which depends on the position of the moon's nodes; its extent is about 9″·2, and its period is nearly 19 years, the same period as that of the revolution of the moon's nodes. (2) *Solar nutation*, which depends on the position of the sun in the ecliptic; its period is therefore 1 year, and its extent is only 1″·2, so that the solar nutation is much smaller than the lunar nutation, and in the figure would be represented by small 'ripples' on the 'waves' which represent lunar nutation, 19 'ripples' to each 'wave.'

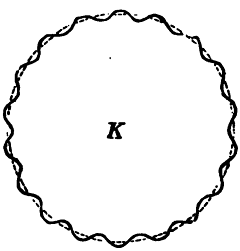


FIG. 134.

183. **Different kinds of Year.**—1. *The Sidereal Year* is the one representing the true orbital revolution of the earth. It is the time the sun appears to take to travel round from one star back again to the same star. Its length is 365 days, 6 hrs., 9 ms., 9 secs.

2. *The Tropical or Equinoctial Year.*—For ordinary calendar purposes this year is chosen because the seasons depend on the sun's position with regard to the equinoxes. It is the time the sun takes to move round from one equinox back to the same equinox. Since the equinoxes advance to meet the sun, this is shorter by about 20 minutes than the true or sidereal year. Its length is 365 days, 5 hrs., 48 ms., 46 secs.

3. *The Anomalistic Year* is the time from perihelion to perihelion. As perihelion moves slowly eastward, this year is a little longer than the sidereal. Its length is 365 days, 6 hrs., 13 ms., 48 secs.

Since the equinoxes advance 50″·2 annually, and the line

of apsides retreats $11''\cdot25$ annually, the relations between these three different kinds of year can be put in the form :

$$\begin{array}{cccccc} & \text{sidereal year} & : & \text{tropical year} & : & \text{anomalistic year} \\ = & 360^\circ & : & 360^\circ - 50''\cdot2 & : & 360^\circ + 11''\cdot25. \end{array}$$

The civil year now begins on January 1 and consists of an integral number of days, which must, however, retain a close connection with the tropical year. This can be effected by having civil years of two different lengths, the one less and the other greater than the tropical year, a common year of 365 days and a leap year of 366 days, the order of succession of these two years being regulated by the rule laid down by Pope Gregory in 1582. This rule may be thus expressed : All years whose date-number is divisible by 4 without a remainder are leap-years, unless the year terminates a century. Only those years terminating a century are leap-years in which the hundreds are divisible by 4 without a remainder. Thus 1,600 and 2,000 are leap-years, but 1700, 1800, 1900 are not leap-years. By this rule the seasons, as determined by the position of the sun, will be kept to their proper months, and the dates at which they commence will be the same for a long period. 'In 400 years, as determined by the Gregorian rule, there will be 97 leap-years instead of 100, and the average length of the civil year will be $365\frac{97}{400}$ days, or $365\cdot2425$ days. The tropical year contains $365\cdot242216$ days, so the Gregorian rule makes the average civil year too long by $0\cdot000284$ days, producing an error of 1 day in about 4,000 years.'

CHAPTER XI.

MEASUREMENT OF THE SURFACE, SIZE, AND SHAPE OF THE EARTH—MASS OF THE EARTH—DETERMINATION OF LATITUDE AND LONGITUDE.

184. THE object of geodetical surveys, or geodesy, is the measurement of the Earth's surface, size, and shape. The standard of measurement in England is the yard, or its multiple the mile, or submultiple the foot and inch. The first essential step is the accurate measurement of a *base-line*. As all future calculations depend on this preliminary length, its accuracy must be the greatest possible. But here is a difficulty at once. Some measuring-rod must be chosen, and whatever its substance, heat will make it expand and cold contract, so that its length is always varying as the temperature changes. This will make it unsuitable for accurately measuring a distance which is *many times* its own length. This difficulty must be got rid of

in some manner. One suggested method was to compare the metal bars that were used with some standard bar at known temperatures, and make allowance for the changes due to different temperatures. A better method was invented by Colby for constructing a compensating apparatus which should give an invariable length.

This consists of two parallel bars of iron and brass, 10 feet long (fig. 135), firmly connected at their middle by two transverse cylinders. At both ends there is a metal tongue pivoted to both bars about the points *a*, *b*, *a′ b′*, firmly attached though allowing the bars to expand freely. A silver pin let into each tongue carries a small dot *c*, or *c′*; and it is the distance *c c′* which serves for the required invariable standard of measurement. This freedom from variation is secured by making the ratios *a c* to *b c* and *a c′* to *b c′* the same ratio as the expansion of the brass rod *a a′* to the iron rod *b b′*. Then when *a* by ex-

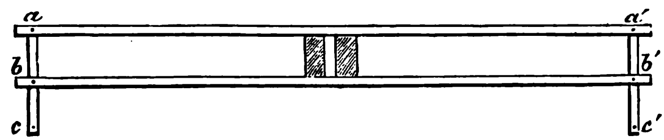


FIG. 135.—Colby's Compensating Apparatus.

pansion moves off to the left, *b* does not move so far, and the tongue *a b c* gets tilted, leaving *c* in exactly its original position, and similarly for *c′*. The same holds for contraction when *a* moves further to the right than *b*, but leaves *c* in its true position. The distance *c c′* thus remains constant. To ensure the correct working of this compensation apparatus it was necessary to make the bars absorb and radiate heat at equal rates. This was effected by varnishing their surfaces until experiment showed they had the same rate of heating and cooling. The method of working with the bars will be indicated below under measurement of base-line.

185. **Ground for Base.**—This must be fairly level, and if necessary further levelled, free from obstacles, its two extremities mutually visible, and two or more distant stations for extension of survey must be visible from both extremities. The British base-lines chosen were one on the shores of Lough Foyle in Ireland, of length 41,614 feet, and another on Salisbury Plain of length 36,578 feet. Other accurately-measured base-

lines have been used in different countries: one, in East Prussia, of a little more than a mile; one, in France, about 11·8 miles; and ten in India, varying from 1·7 to 7·8 miles.

186. **Measurement of Base.**—This is accomplished by the use of two or more of the compensating bars.

The extremities of the line are definitely marked by a fine mark on a massive block of stone firmly set in brickwork. This mark is a microscopic cross drawn on the surface of a piece of brass cemented into the stone, or else a dot on the end of a platinum wire set vertically in a lead block let into the stone. The process of measurement consists roughly of laying one rod down, in a line pointing between the two extremities of the base, then laying at the end of the first a second rod in the same line, then a third, six bars being sometimes used. The first is then taken up and applied to the end of the last, just as one may measure with foot-rules. But here extraordinary precautions to ensure accuracy must be taken. To begin with, the rods must not touch, for fear of disturbing one another. They are left about six inches apart, and the distance between their extremities (the microscopic dots on the tongues) is measured by means of

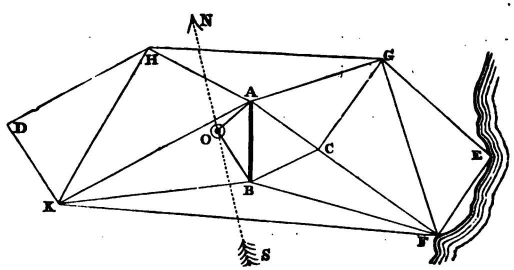


FIG. 136.

microscopes which are mounted on the same principle of compensation. They are to be laid perfectly horizontal by spirit-levels, and placed exactly in the straight line joining the extremities of the base by a directing telescope. Possibly owing to the inequality of the ground, the one bar may have to be higher than the other, but both must be horizontal, and it is the horizontal distance between their extremities, and consequently between the extremities of the base, that is to be measured. Further the bars are kept under cover of a tent, to be sheltered from the sun's rays as far as possible. Having accurately accomplished the measurement of the base-line, it serves the purpose its name indicates, viz. a base, or starting-place, for measuring or calculating other distances.

Triangulation is the name applied to the process of calculating these distances by measuring the angles of triangles. Figure 136 will explain this. A B is the measured base-line, O and C two stations visible from its extremities, D E, &c., other stations observable from one another, and the lines joining which cover up the country with a network of triangles. The stations are conspicuous objects, such as cairns, mountain-tops, &c. The angles of the triangle A C B are measured by the *theodolite*. Knowing the angles and one side A B, we can, by trigonometry, calculate the other two *CA, CB.* These then in their turn will serve as new base-lines for measuring

other distances by the observations of the angles of further triangles; for example, having found A C and B C we measure the angles and calculate A G and C G, and then H G, &c. Proceeding in this way many distances may be calculated, all derived from the original base, and the triangulation may be extended, till a complete map of a country would be constructed accurately to scale. Two important points, however, must be borne in mind.

1st. The triangles must be well chosen, so as to ensure the greatest possible accuracy, and for this purpose their sides must be fairly equal, or at any rate not very unequal in length. For triangles with very unequal sides will have at least one small angle, a small error in the measurement of which will cause a large proportionate error in the calculated lengths of the sides. With well-chosen triangles the first series of triangles will have sides which are only some few miles long. But as the series extends, larger and larger triangles may be used, till we get to sides of 100 miles long or more, as the 111 miles from Sca Fell Pike in Cumberland to Slieve Donard in Ireland. (For such long distances the weather must be very favourable to observe the signals, which are reflected sunlight or powerful artificial lights.)

2nd. The second point to observe is that these triangles are not plane triangles, but are on the surface of a sphere (approximately). The consequence noticed is that the three angles of the triangles make up more than 180°; and, indeed, this is a guide that the observations are correct. See par. 8. This causes immense intricacy in the necessary calculations for the lengths of the sides of the triangles, and the labour of this calculation is immense. Nevertheless, it is done with wonderful accuracy, and the triangles are so interlaced that one is being continually used to check and test the accuracy of the others. In this way, too, the length of the base itself may be checked. For instance, we have the two measured bases of Lough Foyle and Salisbury Plain, the former nearly eight miles, the latter nearly seven miles long. Through a most intricate series of triangles, the length of the Salisbury Plain base was calculated upon that of Lough Foyle, with a result which was less than five inches from its measured value. This error was divided equally between the bases and the connection applied to the whole triangulation. Another example of the accuracy of allowing for the different elevations of the stations is that the height of Ben Mac Dhui was calculated to be 4,295·6 feet, and measured by means of the spirit-level to be 1½ inches more.

In the principal Triangulation of the British Isles, the average length of the sides of the triangles was 35·4 miles; and the sum of the lengths 206,710,000 miles. The principal triangles were subdivided into secondary ones, with sides of ten or fifteen miles; these again into tertiary triangles of about one mile, and then ordinary chain-surveying was done. In this way the maps of the Ordnance Survey were made.

187. **Size of the Earth.**—Besides being of use for purposes of map-making, geodetical observations give the size and true shape of the earth. In this latter purpose they must be connected with astronomical observations after a careful *measurement of the arc of a meridian.* This measurement is effected by choosing two of the stations in the system of triangulation

so that the one is due north of the other. Then all the necessary trigonometrical calculations of this meridional arc are made, and to ensure accuracy, a base of verification is measured, and must have its calculated value. The *geodetical* work is then finished, and gives the linear distance between two stations on the same meridian. The astronomical work consists in finding the difference of latitude of two stations. The latitude of each station may be found by the usual astronomical means ; or the difference in latitude may be found more simply. The zenith distance of the same star when on the meridian must be measured at both stations by the use of the *zenith sector* (par. 51), and the difference between these two zenith distances

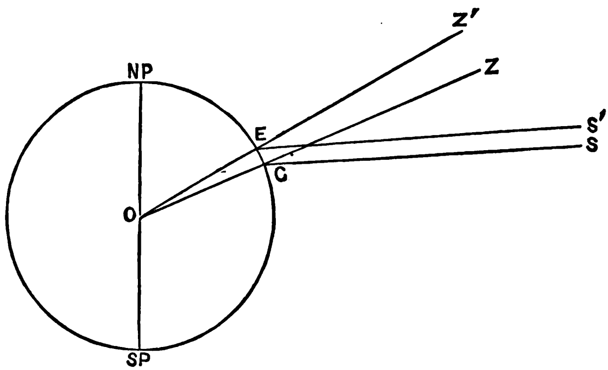


FIG. 137.

gives the difference of latitude of the two stations, which is the angular value of the arc measured.

Let fig. 137 represent a plane section of the earth through the centre and the poles so that the circle shown is a meridian. The distance E G on this meridian has been found in miles by geodetical work. We want to know the value in arc of E G, that is the number of degrees in the angle E O G. The line O G Z is the *vertical* line at G, as found by the plumbline, and O E Z′ the direction of the vertical at E. When a fixed star is on the meridian at G, it is also on the meridian at E, and the lines G S and E S′, pointing to this infinitely distant star, are parallel. An observer at G measures the angle S G Z by the zenith sector when the star is on the meridian, and at the same time an observer at E measures the angle S′E Z′. These angles are the zenith distances of the star at the points G and E, and the *difference* of the two angles is the angle G O E, which gives us the number of degrees in the arc G E. Let this arc be 9° 24′, and let the distance

G E, measured in miles, be $645\frac{1}{3}$. We have then the simple question: If $9° 24'$ give a length of $645\frac{1}{3}$ miles, what will be the length of 1°. The result is 69·7 miles nearly. This measurement of an arc of one degree on the meridian is the foundation of the subsequent calculations, and the great care taken in measuring the base-line, and in the work of triangulation, enables us to obtain this length accurately to a few feet. Knowing the value of 1°, it is easy to find the value of the whole circumference, or 360°.

188. **Shape of the Earth.**—Several arcs have been measured, some twenty or thirty in different parts of the world: an Anglo-French one of more than 12°, an Indian of 18°, a Russo-Scandinavian of 25°, and shorter ones in South America and South Africa, and it is found that *the length of a degree increases as we pass from the equator towards the poles.* Near the equator the degree is about 362,800 feet, but in North Sweden, lat. 66°, it is 3,000 feet longer. That is, in the north or south it would be necessary to travel farther to get a difference of 1° in the altitude of the celestial pole, than it would be near the equator. This proves that the earth is flatter near the poles, and its shape, instead of being a sphere, is an oblate spheroid, and it is found that the polar diameter is about 27 miles shorter than an equatorial diameter. Arcs of longitude are also suitable for obtaining the size and shape of the earth, and indeed arcs between any two stations of which both the latitude and longitude are known, may be estimated. With these further measurements it has been found that the earth is not even a true spheroid. The equator is not quite circular, but is itself elliptical, having one diameter slightly longer than the other at right angles; but this is not nearly so noticeable as the flattening of the poles. Such a figure, with three axes of different lengths, is called an ellipsoid.[1]

According to Colonel Clarke, the true dimensions of the earth are

Equatorial semi-diameter,	3,963·296 miles	=	20,926,202 feet
Polar semi-diameter,	3,950·738 „	=	20,854,895

Ellipticity or Polar compression, $\frac{1}{293{\cdot}46}$

189. **Surface and Volume of the Earth.**—The earth is so nearly a sphere that we can now determine the area of its surface, and its bulk or

[1] See note, page 329.

volume, from the known properties of a sphere—surface $= 4\pi r^2$ and volume $= \frac{4}{3}\pi r^3$, where r is the radius of the sphere. Putting the earth's mean semi-diameter for r, it is found that the surface is 49,240,000 square miles, and the volume 260,000 million cubic miles—in round numbers.

190. **Weighing the Earth and finding its Density.**—Since the weight of the earth is merely the product of its volume and density, and its volume is now known, these questions are identical. There are three fairly satisfactory ways of finding out the weight of the earth. All depend on the principle of gravitation, and roughly all three are methods of comparing the earth's attraction for some body with the attraction of a known mass or weight for that same body. The details of experiment, however, vary widely. We shall now point out the method of procedure for each of the three. It must, of course, be understood that most careful and intricate precautions to ensure accuracy are necessary for these experiments; but into these we have not space to enter.

191. **The Schehallien Experiment.**—This experiment was so called because it was carried out on the Schehallien mountain in Scotland, in 1774, by Dr. Maskelyne. In the experiment, the attraction of the earth was weighed against that of the mountain by ascertaining how much the local attraction of the mountain deflected a plumbline from the vertical position. Two stations on opposite sides of the mountain were chosen so that the one was due north of the other. The difference of their geographical latitude was measured accurately by actual geodetical measurement. This determines the angle between the two vertical lines P A and Q B. But a plumbline, P V, over A is pulled slightly out of its vertical position to P V′ by the attraction of the great mountain mass M, and the plumbline Q W over B is similarly pulled to Q W′. The distance of astronomical latitude is found by measurement of zenith distances of stars. These measurements depend on what seem to be the vertical lines at A and B, viz. P V′ and Q W′; and not on the actual vertical lines P V and Q W. This difference of astronomical latitudes gives the angles between the plumblines P V′ and Q W′. The difference of geographical latitude, or angle between P V and Q W, was found to be 41″, while that of astronomical latitude or angle between P V′ and Q W′ was found to be 53″ So that the angles V P V′ and W Q W′ being equal were each 6″. So that the mountain's attraction on a plumbline pulled it out of its true vertical by 6″. Careful measurements of the surface of the mountain were made in order to calculate its volume; and also the rocks were carefully examined to estimate their average density. The two would then give the mountain's mass, and the problem then was to estimate the ratio of the mass of the earth to that of the mountain so that the latter could produce this deflection of 6″ in the plumbline. By this means the density of the earth was found to be 4·71, a result not closely agreeing with other and better experiments. (The weakness of the method lies in the estimation of the average density of the rocks, which cannot be accurately determined.) A repetition of the experiment on Arthur's Seat near Edinburgh gave a better result, viz. 5·32.

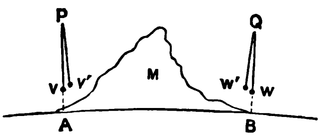


FIG. 138.

192. **The Cavendish Experiment.**—This is the method of determining *the earth's mass* and density by means of a torsion balance, and was first

employed by Cavendish in 1798. It depends on measuring the attraction of two large masses of lead on two small ones placed at the ends of a light rod which is delicately suspended by means of a fine wire fastened at the centre. In fig. 139 *a* and *b* are the two small balls fixed on the end of a light bar which is suspended horizontally about its middle point *c* by a long fine vertical line. If the rod is turned through a small angle it twists the wire, and on being released it vibrates about its mean position till reduced to rest by the friction of the air. The time of oscillation will determine the force of torsion of the wire, i.e. the force which it exerts to prevent itself being twisted. Now when *a b* is in its mean position the two large balls A and B are put in their positions near the small ones *a* and *b* as in the figure. Then A attracts *a*, B attracts *b*, and the rod is deflected from its mean position, until the force of torsion, which increases the more the wire is twisted, counterbalances the attractive forces of the balls. The new position of the balls *a* and *b* is carefully noted. Then A is moved to A′ on the other side of *a*, and B to B′ on the other side of *b*; and there is now a slight deflection in the opposite direction, equal to the former, again carefully noted. The difference in position of *a* for the two deflections when measured gives twice the deflection produced by the balls in the first or second positions. As a matter of fact in actual experiment it was found that the apparatus was never at rest; but the true position for any observation was found by observing the length of swing of the rod, and taking the mean of the extreme positions. In this way the required deflections could be accurately obtained, without tedious waiting for the rod to come to rest. Now the previous experiments give the force requisite to produce this deflection or twist in the wire; and this force is, of course, equal to the attractive forces of the balls, which therefore are now known. That is, we now know the attractive force of the ball A, of known mass or weight, on the ball *a*. The distance, say *x*, between their centres has to be most carefully measured, and since the balls attract just as if their whole masses were collected at their centres, we have now all data for calculation. Thus the ball A attracts *a* at distance *x* with a known force. We can calculate what would be the attraction of A or *a* at a distance equal to the radius of the earth. But the earth's attractive force at this distance on *a* is the weight of *a*. The ratio of the masses of A and the earth is the ratio of their attractive forces on *a* at equal distances. Hence we know how many times the earth is heavier than A. This method is better than any other, and by it Cornu obtained 5·56 as the earth's density—a result as accurate as we can hope to get.

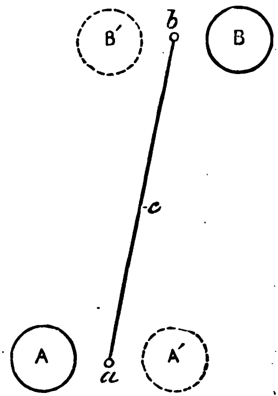


FIG. 139.

His apparatus differed in form from the above, as his heavy balls were four hollow iron spheres suitably placed near the small balls, and which could be alternately filled with mercury and emptied. By this means he avoided the shifting of the balls. (To indicate the delicacy and subsequent care required *for this experiment*, it will be sufficient to observe that it is

requisite to measure a force equal to a hundred-millionth part of the weight of the small ball).

193. **The Harton Pit Experiment.**—This was devised and carried out by Sir G. Airy. It depends on observations of the difference in the time of swing of a pendulum at the top and bottom of a mine. The time of the complete swing of a pendulum, the 'swing-swang,' is given by the formula. $\text{Time} = 2\pi\sqrt{\frac{\text{length of pendulum}}{\text{force of gravity}}}$. Now when at the bottom of the mine the mass of earth above has no longer a downward attraction on the pendulum-bob, and so the force of gravity on it is diminished, with a consequent change in the time of swing. At any point within a hollow spherical shell, supposed to be homogeneous, it can be proved that the attraction of the shell is zero. So that as far as gravity is concerned, the effect of going to the bottom of the mines was, as it were, to strip off a shell of the earth equal in thickness to the depth descended. But being closer to the centre of the earth slightly increases the force of gravity. The pendulum at the bottom of the mine will therefore move faster because nearer the earth's centre, slower because of the shell stripped off; and on the whole slower because the effect of the latter is greater than that of the former. The observed times of swing at the top and bottom of the mine will give the ratio of gravitational force of the whole earth, and of the earth with its shell stripped off. If then we can determine the mass of the shell accurately we can determine that of the earth. We have supposed the shell homogeneous; it would not be likely to be so round the whole earth, or even in any considerable part. The part of the shell near the mine is practically the only part that changes the gravitational force; and the best possible estimate of its average density was made by observation of the character of the rocky strata. Then was deduced the relation between the density of the earth and that of the shell. The result found for density of the earth was 6·56, a value now generally held to be too high. Other methods of finding the density of the earth have also been devised, and as a result of the best experiments it may be taken that the density of the earth, is about 5·58. It is remarkable that Newton, in one of his prophetic guesses, put down the density as between 5 and 6, long before experiments to determine it were tried. The weight of the earth, being deduced from the product of its volume and density, is about 6,000,000,000,000,000,000,000 tons, 6 followed by 21 ciphers. But this must be clearly understood. Mass is a property of matter independent of attraction; weight depends on attraction —usually on the attraction of the earth at its surface. So to say that the earth weighs so many tons practically means that if you were to take a cubic yard of the earth's substance, weigh it on the surface of the earth, then put it back in its place, take another cubic yard, weigh and replace it, and so on till every part of the earth has been brought to the surface and weighed, then the sum of all the weights may be looked on as the weight of the earth.

194. **Determination of Latitude.**—To know our position on the earth's surface it is necessary to ascertain the latitude and longitude of the place on which we stand. The latitude of a place is often defined in geography as the distance north or south of the earth's equator measured in degrees. It may be better regarded as the angle between the perpendicular to the horizon of any place and the plane of the earth's equator. In fig. 140 let C denote the centre of the earth and R a point on the earth's surface. Through C draw a line towards the celestial pole and cutting the surface of the earth at the north and south poles. Through C

draw also a plane perpendicular to C P, to represent the earth's equator, and draw C R Z through R. This line will be perpendicular to the tangent plane R A which denotes the horizon at R. Then by definition the angle R C H is the latitude of the place R. The observer at R sees the celestial pole in the direction R Q, which is parallel to C P, owing to the enormous distance of the fixed stars. At the point R in the straight line H R Q we have the angle A R C, equal to a right angle, and therefore the angles Q R A and H R C together equal to another right angle, and since in the triangle R H C, the angle at H is a right angle, therefore the angles H R C and R C H are together equal to another right angle. Hence the angles Q R A + H R C = the angles H R C + R C H. Taking away the common angle H R C it follows that the angle Q R A must be equal to the angle R C H, that is, *the elevation of the pole above the horizon is equal to the latitude of the place.* To determine latitude, therefore, we only need to find the elevation of the pole. This can be done exactly by measuring the altitude of any circumpolar star at its upper and lower culminations, correcting both observations for refraction. The mean of the two altitudes thus corrected gives the latitude of the observer. We may also find the latitude by measuring the altitude of a star when passing the meridian, if its declination is obtained from the Nautical Almanac. The complement of the declination thus obtained is the polar distance, and if we add the observed meridional altitude to the polar distance and then deduct the sum from 180° we get the elevation of the pole—that is the latitude. At sea, where fixed instruments cannot be employed, the latitude is usually determined by observing with the sextant the meridian altitude of the lower limb of the sun or moon. To this altitude we must add the semi-diameter of the body and correct for refraction and dip. The result *plus* the sun's declination (obtained from the Nautical Almanac) if south of the equator, or *minus* if north, will give the elevation of the equator, which is the complement of the latitude.

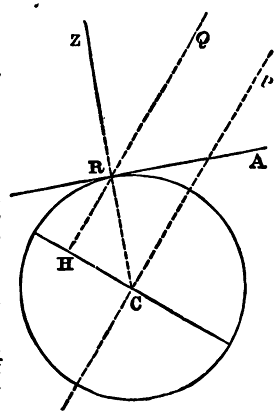


FIG. 140.

195. **Determination of Longitude.**—Terrestrial meridians are great circles passing through the poles, and the longitude of a place may be defined as an arc of the equator intercepted between some selected meridian and the meridian passing through the place. It may also be regarded as the angle subtended at the terrestrial pole by this arc. Longitude is measured 180° east and west of the selected meridian—that of Greenwich. As the earth rotates uniformly from west to east, it brings the sun to the meridian of any place every 24 hours; therefore $\frac{360°}{24}$, or 15°, is the space of the earth's surface passed over by the sun in one hour, or one degree in 4 mins. of time. Longitude may therefore be expressed when we know the amount by which its noon is earlier or later than noon at Greenwich. The local sidereal time can be obtained by observing the transit of a star whose right ascension is known, and then converting this into *mean solar time.* At sea, the time is usually determined by finding

the apparent noon by observation of the sun's meridian passage, and from this mean noon will be obtained by applying the equation of time with its proper sign. Knowing the local time at any place it is easy to find its longitude if we can compare it with Greenwich time at the same moment. Greenwich time is often obtained from a well-regulated *chronometer*. This is a method much used by mariners. Having found the time, at a certain position, the chronometer is observed for Greenwich time, and the difference of the two times at once gives the longitude. Thus if the local time be 10 A.M. when the Greenwich time is 1.12 P.M. the longitude is 48° W. The best method on land is the method by *electric telegraph*. This enables two observers to ascertain the difference of time at any instant as shown by their respective clocks accurately adjusted to local time. This gives the difference of longitude, so that if the longitude of one station is known that of the other can be exactly determined. Another method of finding the longitude of any place is the method of *lunar distances*. Certain pages of the Nautical Almanac contain, for every third hour of Greenwich mean time, the angular distances of the apparent centre of the moon from the sun, the larger planets, and certain stars, as they would appear from the centre of the earth. The observer at sea measures with his sextant the distance of the moon from one of these stars. This lunar distance is reduced to the centre of the earth by clearing it of the effects of parallax and refraction. Knowing the local time (from other observations) at which the lunar distance was measured, he finds in the Almanac the Greenwich time at which the lunar distance of this star was the same. The difference between the local time and the Greenwich time gives the longitude of the place of observation.

CHAPTER XII.

CELESTIAL MEASUREMENTS.

196. Having obtained a measurement of the size of the earth, it remains to be seen what knowledge we can gain of the distances of the different celestial bodies. At first sight it may appear strange that we are expected to measure such distances, because these celestial bodies cannot be reached. But our geodetical measurements will have given us some idea of the methods to be pursued. For in the system of triangulation it will be understood that by measurement of the distances between two accessible stations A and B, and observation of the angles formed at A and B by lines from a third inaccessible station C, we can calculate the distance from either A or B to C without ever going to it—that is, if we know the length of one side of a triangle and also the size of the angles of this triangle,

we are able to estimate the lengths of the other sides. This method is most easily and accurately applied in the case of the nearest of the heavenly bodies, viz. the moon. The process is called finding the *parallax* of the moon. This we will explain at greater length.

197. **Parallax.**—An observer looking out from the window of a room may see that some outside object, a tree or chimney it may be, is directly behind a particular mark, as a crossing of the woodwork in the window. When he moves from his first position, his mark on the window will seem to change also, no longer covering the first external object, but moving on to some other. This apparent change of position of a body relative to some distant background, but due to a real change of position of the observer, is called the *parallax* of that body. In astronomy we use this term in a more restricted sense, to be defined shortly. We are continually noticing this parallax, and, indeed, estimate distances of near objects by their change of position, as seen from the two eyes. For if the finger be held up, and the eyes be alternately closed, the right eye will see it in front of one distant body, and the left eye in front of quite a different one. The angular displacement of a near object in this way is considerable, and the muscular effort necessary to converge both eyes to it gives some idea of its nearness. Why do we say this only applies to near bodies? Because the angular displacement or parallax for distant bodies is extremely small for such a small change of position of observation as from one eye to the other. Roughly speaking, the parallax of

$$\text{a body} = \frac{\text{change of position of observer}}{\text{distance of body}}.$$

If then we are to estimate large distances, such as that of the moon, we must take two stations as far apart as possible, so that we may make the parallax or angular displacement to be measured as large as possible, and so less liable to error in measurement. Now as all observations of heavenly bodies are made from different positions on the earth's surface, we must understand that the positions of the nearer heavenly bodies, as seen projected on the background of the heavens, will vary according to the position of the observer. So that all numerical indications of position of such bodies would necessitate a statement of the exact position of each observer, and without due allowances would not be accurate for an observer in another position. To avoid all such difficulties the positions are put down as they

would appear to an observer at the centre of the earth. The position of the heavenly body to any observer on the earth's *surface* is called its *apparent* position; the *true* position being that in which it would appear to an observer at the *centre* of the earth. All observations are reduced from apparent to true position, the correction being called correction for parallax. Thus the *parallax of a heavenly body* is the angle between two lines drawn to it, one from the observer and the other from the centre of the earth; for this angle is a measure of the displacement on the distant celestial sphere due to this change of position, and the angle will evidently be smaller the more distant the object is. Thus in fig. 141, O is the observer, with his zenith in direction C O Z, C the centre of the earth and S the heavenly body. The angle Z O S is the zenith distance. The angle O S C is the parallax. When the body is on the observer's horizon, as at S′, then the angle C O S′ is a right angle, and the angle O S′ C is now called the *horizontal parallax*. When the body is vertically over the observer there is no parallax. Parallax increases with the zenith distance of the body, being greatest on the horizon, i.e. the horizontal parallax is the maximum. Another way of considering horizontal parallax is to look on it as the angle subtended at the celestial body by a radius of the earth; and double the horizontal parallax is the angle subtended by a diameter of the earth or the angular magnitude of the earth as seen from the celestial body. As the earth is not a sphere but a spheroid, its radii differ slightly. It is usual to refer in horizontal parallax to an equatorial radius as the base line of observation. This is then called the *equatorial horizontal parallax*. The *equatorial horizontal parallax* may, therefore, be defined as the greatest angle at the centre of a heavenly body subtended by an equatorial radius of the earth. As the angle C O S′ is a right angle, therefore sine O S′ C = $\frac{OC}{CS'}$. If the point O be on the equator, this gives the relation:—sine (equatorial horizontal parallax) = $\frac{\text{equatorial radius of earth}}{\text{distance of heavenly body}}$, the distance being measured from the centre of the earth. The distance is also given by $D = \frac{206265 \times R}{\text{parallactic angle in seconds}}$ (see par. 3).

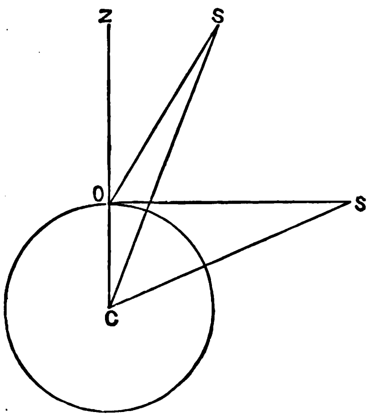


FIG. 141.

As we know the equatorial radius of the earth, this trigonometrical relation will give us the distance of the heavenly body when once we have measured the angle called its equatorial horizontal parallax. Thus the determination of the distance of a heavenly body resolves itself into the determination of its parallax. For all heavenly bodies except the moon,

the distances are very large, and the angle to be measured so extremely small that the greatest instrumental refinements are necessary, whilst a small error in measurement of this small angle will produce a large error in the calculated distance. But in the case of the moon, which is comparatively near, the angle to be measured is larger, and a small error of observation does not give such a large percentage error in the calculations. Hence we said that the method of parallax was more easily and accurately applied to the distance of the moon than that of any other celestial object. We will now indicate the method as applied to the moon.

198. **Determination of Parallax and Distance of Moon.**—For this purpose two places of observation, as far distant, and as nearly on the same meridian as possible, are chosen; for example, the observatories at Greenwich and the Cape of Good Hope have been used. Let G and H represent these two places of observation, supposed to be on the same meridian, N G H S. N C S is the axis of the earth, C its centre, G p, H p' are two lines

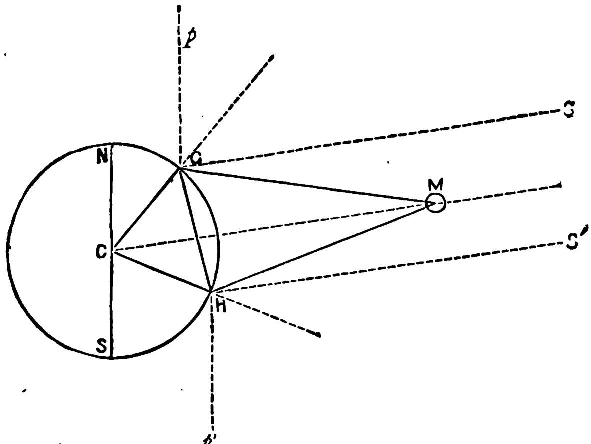


FIG. 142.

pointing respectively to the north and south poles of the heavens at G and H; and so both lines are parallel to N S. M is the moon. G S and H S′ are the directions of the same star, S, some star on the meridian and near to the moon at both stations. As the stars are practically at an infinite distance, the directions G S and H S′ are parallel. The figure is exaggerated; in reality the angles S G M, S′ H M will both be very small. At each station the differences in the polar distances of M and S are measured by the transit circle. Thus at the northern station, the difference between M G p and S G p is measured when M and S cross the meridian, giving us the angle M G S, and at the same time and in the same way the angle S′ H M is measured at the southern station. Because G S and H S′ are parallel, S G M + S′ H M = G M H. Therefore we get from the observations the angle G M H, which is the parallax of the moon due to change of point of observation from G to H. Moreover we know the angle G C H, which is the sum of the northern latitude of Greenwich and southern latitude of the Cape; and we know

C G, C H, the radii of the earth at G and H. So now we have sufficient data for the trigonometrical calculation of any of the distances G M, C M, or H M.

As an illustration, suppose the angle p G M between the north celestial pole and the moon measured at G was 101°, and the corresponding angle p' H M at H, between the moon and the south celestial pole, 80° 26′ 22″. Then p G M + p' H M = 181° 26′ 22″. Now, if instead of the moon, the immensely distant fixed star S had been observed at G and H, 180° would have been the result, as G S and H S are by supposition parallel. Hence the angle G M H = 1° 26′ 22″. Calling the distance G H 6,000 miles, we get a parallax of 1° 26′ 22″, or 5,182″ with this base-line. From this may be deduced the angle subtended at the centre of the moon by the earth's equatorial radius, 3,963 miles. This is the moon's equatorial horizontal parallax, and from many careful measurements, this angle has been found to have a mean value of 57′ 3″ or 3,423″. From what has been said in paragraph 3, we see that the moon's distance may be determined from this parallax. We have, calling R the radius of the earth, moon's distance = $\frac{206265 \times R}{3423} = 60\frac{1}{4}$ earth's radius, nearly = 238,800 miles.

In this way it has been found that the moon's distance from the centre of the earth varies between 259,972 miles and 221,614 miles; the mean distance being 238,840 miles, or about $60\frac{1}{4}$ times the equatorial radius of the earth. Since sine (equatorial horizontal parallax) = $\frac{\text{equatorial radius of earth,}}{\text{distance of moon}}$ we find that the mean equatorial horizontal parallax of the moon is 57′3″, or nearly 1°. Or, as we may put it, the earth's diameter would subtend an angle of 2° to an observer on the moon.

(*Note.* Two stations with suitable observatories cannot be found exactly of the same longitude; but the method above explained is applied with the extra corrections needed, such as that due to a change of polar distance of the moon during the interval between its transit over the two meridians.)

199. **Determination of the Size of the Moon.**—Once having obtained its distance, we have merely to measure its angular diameter and we can get its magnitude (see par. 3). Its mean angular diameter is 31′ 7″. This corresponds to a diameter of 2,163 miles, about $\frac{3}{11}$ of the earth's diameter. Since the surfaces of globes vary as the square of the diameter, we find the surface of the moon rather more than $\frac{1}{13}$ of the surface of the earth; and as the volumes vary as the cubes of the diameters, the volume of the moon is about $\frac{1}{49}$ that of the earth.

It must be noticed that the moon's distance is no basis for other measurements, as it has no relationship to other distances in the solar system. Quite different is the case of the sun's distance, as this serves for an excellent base-line for measurements both in, and beyond, the solar system.

200. **Distance of Mars.**—A method of parallax similar to that used in finding the moon's distance has been applied to the planet Mars. Favour-

able opportunities are taken when Mars is in opposition, for then Mars and the earth are nearest together. The most favourable oppositions are when Mars is at perihelion and the earth at aphelion, as the two planets are then at their minimum distance. Such was the case in 1877, and will be again in 1892 and 1894. In observations for the parallax of Mars, one observer has been found sufficient. He makes two observations at an interval of some hours, the rotation of the earth supplying the requisite base-line. Suppose, for example, the observations are made at the equator, the first when Mars is rising, and the second when he is setting. In this case, the second observation will be made at a distance of nearly 8,000 miles from the first, the rotation of the earth having carried the observer this distance from the point of his first observation. Mars will thus be made to undergo an angular change of position, and this is the parallax to be measured. Fig. 143 illustrates the displacement of Mars in such a case. The lower G and the upper G′ represent the positions of an observer at the equator at an interval of 12 hours. As seen from G when Mars is rising, the planet appears at *s* to the east of the distant fixed star S, and this eastward displacement is measured. The star is one which has really the same declination as Mars, and which therefore appears in the same position from all points of the earth. As seen from G′—the upper G—when Mars is setting the planet appears at *s*′, and this westward displacement is measured. The angle *s* M *s*′, which is equal to G M G′, is thus determined, and this angle is the angle subtended at the centre of Mars by the diameter of the earth. By definition, then, half this angle is the equatorial horizontal parallax of Mars; and knowing this (about 22″) and the radius of the earth we can find the distance of Mars from the earth at the time of opposition. The result thus found gives the average distance of Mars from the earth at the time of opposition as 48,600,000 miles.

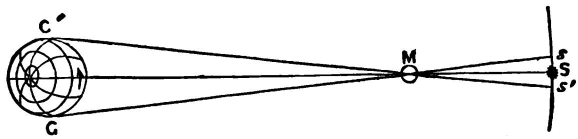


FIG. 143.

201. **Solar Distance and Parallax Deduced from distance of Mars.**—The importance of this method is its indirect result in giving us the distance of the sun and the solar parallax. No accurate means of directly measuring the parallactic displacement of the sun has been devised, for the sun's limb is a bad object to point on, and its heat further disturbs the instrumental adjustments. But in the present case we may obtain the sun's distance by making use of Kepler's Third Law of Planetary Motions. Calling E the mean distance of the earth from the sun, and M the distance between the earth and Mars at opposition, then E + M is the mean distance of Mars from the sun.

By Kepler's Third Law

$(E+M)^3 : E^3 :: (\text{length of Mars' year})^2 : (\text{length of Earth's year})^2.$

$$(687)^2 \qquad\qquad (365\tfrac{1}{4})^2$$

From this we can determine the value of E when M is known, and the sun's parallax is determined from the equation,—

$$\text{sine (sun's equatorial horizontal parallax)} = \frac{\text{equatorial radius of earth}}{E}.$$

Making all the needful corrections, Dr. Gill obtained from a number of measurements made at the opposition of 1877, a solar parallax of 8″·783, corresponding to a mean solar distance of 93,080,000 miles, a result which may be taken as a close approximation to the truth.

202. **Distance of Venus and the Earth from the Sun.**—It might be expected that a method of obtaining the parallax of Venus when in conjunction, or when nearest the earth, could be used, similar to that used for Mars. But unfortunately Venus in conjunction is so close to the sun as never to be visible except in those rare cases when the planet passes as a dark disc across the sun's face. These occurrences are called *transits of Venus*, and come at intervals of 8 years, 121½ years, 8 years, 105½ years, 8 years, 121½ years, and so on. The last was in December 1882; the next will be on June 7, A.D. 2004. For the purpose of observing the transit from different parts of the earth, the various civilised countries have fitted out scientific expeditions at considerable cost. This very valuable method of determining the sun's distance is unfortunately hampered by many serious practical difficulties, so much that of late, perhaps, not so much importance has been attached to it as was the case a few years ago. It will be noticed that this, like all other methods of obtaining the sun's parallax, is an indirect one; for

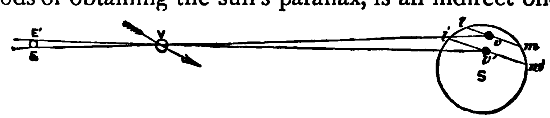


FIG. 144.—Illustrating the determination of the Sun's distance by the Observation of Venus in Transit.

no accurate means of measuring this parallax directly has been devised. It would be entirely out of our scope to do more than *illustrate* the principle involved. The figure will sufficiently

indicate this. V represents Venus passing in the direction of the arrow between the earth, E, and the sun, S.

The sun's disc itself serves as a background on which the parallax of Venus may be measured. But not only is the planet displaced by parallax, but so also is the sun. If the sun were a fixed background, the angle E V E′, through which Venus seems displaced, would be its true parallax. But because the sun also is displaced this angle is the parallactic displacement of Venus relative to the sun; or in other words it is the difference between the true parallax of Venus and the true parallax of the sun. The case of the parallax of Mars was simpler because the background then was a fixed one, viz. the infinitely distant celestial sphere. That this angle will serve our purposes will be manifest from the following course of reasoning. To an observer on the earth at E, Venus appears projected on the sun's disc at v, while to another observer at E′ the planet appears projected at v'. To the first observer the planet's path across the sun appears to be $l v m$, to the second it appears to be $l' v' m'$. The angle E V E′, or its equal v V v' is the first object of our work. Regarding E V E′ and v V v as isosceles triangles, which are similar, having equal angles, and consequently having their corresponding sides proportional, we have—

$$EV : Vv = EE' : vv'$$

But by Kepler's Third Law we know the proportion between E V and V v. It is as 1 : 2·61, and therefore

$$1 : 2{\cdot}61 = EE' : vv'$$
$$\text{or } vv' = 2{\cdot}61 \times EE'$$

Now E E′ is the distance between the two observers on the earth, and will be known. Suppose they are on opposite sides of the earth, so that E E′ is a diameter, and equal to 7,920 miles. The distance $v v'$ has now to be calculated both in miles and in angular measure. This is done by comparing it with the diameter of the sun, for which purpose the positions v and v' are simultaneously recorded, by photography or otherwise, at the two stations E and E′. Now the solar diameter in angular measure is 32′ 4″. It is found that $v v'$ is about $\frac{1}{41{\cdot}8}$ of the solar diameter (the distance $v v'$ is greatly exaggerated in the figure). Then $v v'$ in angular measure is $\frac{1}{41{\cdot}8}$ of $32' \, 4'' = \frac{1924''}{41{\cdot}8} = 46''$ nearly. But we know $v v' = 2{\cdot}61 \times EE' = 2{\cdot}61 \times 7{,}920$ miles $= 20{,}671$ miles nearly. So that at the distance of the sun, 20,671 miles subtend an angle of 46″. But the solar parallax is the angle subtended by the semi-diameter of the earth at the distance of the sun. Therefore the solar parallax is $46'' \times \frac{3960}{20671} = 8{\cdot}8''$ nearly. With this value of the sun's parallax we get the distance from the equation:—$D = \frac{206265 \times R}{8{\cdot}8}$ (par. 3). Taking the value of R, the earth's radius, as 3963·296, we thus find the distance of the sun to be 92,897,000 miles.

The other methods of observation are known from the names of their inventors, Halley and Delisle. Halley's method of coincident path requires that the two stations E and E′ shall be so chosen as to observe the whole path $l m$ and $l' m'$: the time of crossing is accurately taken, and

this gives data for estimating the lengths of the chords $l\,m$ and $l'\,m'$, and therefore of their position on the sun's disc. Then the distance between the two paths is calculated and applied to determine the solar distance after the method given. Delisle's method of non-simultaneous occurrence depends on the fact that at the two stations the planet would just get on to the sun's disc (called the point of internal contact of ingress) at different times. The figure illustrates Venus at Y showing the moment of internal contact of ingress at the point A. Y B represents the path of Venus across the sun's disc, A B C. Favourable points of observation may be chosen, so that the interval between the times of ingress may be the greatest possible; in 1874 it was as much as 25 minutes. The instant, as near as possible, of internal contact is taken at the two stations, and, allowing for difference of longitude, the difference of absolute times will be known. This difference is only due to excess of parallax of Venus over that of the sun, and hence the excess can be calculated, and used, as before, to determine the solar parallax. This second method could be equally well applied to a difference of egress or time of emergence of the planet from the sun, and the method has the advantage of requiring a post of observation for ingress or egress only; whilst Halley's method requires a post of observation for the whole transit, which usually takes more than six hours, during which the observer, if he were not in a properly chosen position, might have the sun setting. Its disadvantage is the difficulty of deciding the exact moment of ingress or egress, owing to optical causes. Both methods have their advantages, and both unfortunately have many disadvantages connected with exact observation. The results of the 1874 transit gave an average distance of the sun equal to about 92,500,000 miles.

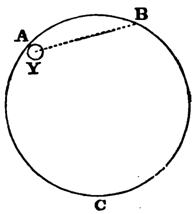


FIG. 145.

203. **Sun's Distance deduced from the Aberration Constant.**—So important is this great base-line of astronomy that many ways of deducing it have been originated. One of interest, and likely to give an accurate result, is based on the principle known as the aberration of light. The aberration of light, as explained in the 'El. Phys.' (par. 299), is, in astronomy, the apparent displacement of a celestial body due to the combination of the orbital motion of the earth and the progressive motion of light. The amount of this displacement depends on the relative velocities of the earth in its orbit, and of light. In consequence of this aberration of light each star appears slightly displaced from its true position. The displacement is always in the direction of the earth's motion. Thus in fig. 146 A B C D represents the earth's orbit about the sun, S. The arrows indicate the directions of motion at the different points. *s* is the true position of a star. In consequence of aberration, when the

at A, the star seems displaced to *a*, *s a* being parallel lirection of the earth's motion at A. Similarly when the at B the star appears to be at *b*, *s b* being parallel to the motion at B. In fact, as the earth describes its orbit the star seems to describe an imaginary small orbit, round its true position, *s*. As Professor Young says,

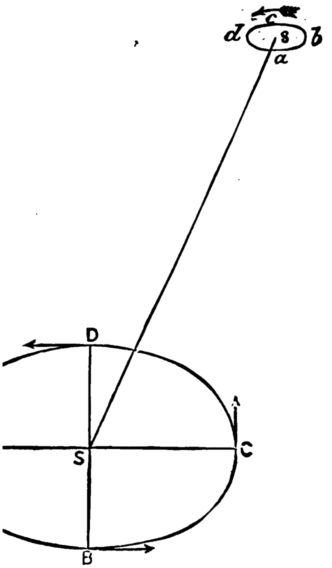


FIG. 146.

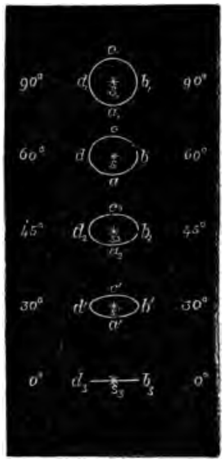


FIG. 147.—Aberration-ellipses of Stars in different Celestial Latitudes.

ırth therefore, so to speak, drives the star before it in the onal orbit, keeping it just a quarter of a revolution ahead f.' When the line *s* S is perpendicular to the ecliptic of the earth's orbit A B C D, the small orbit of the star exactly similar to the earth's orbit; i.e. nearly a perfect As *s* S becomes inclined to that plane, the circle *a b c d* more or less viewed edgeways, and appear as an ellipse, ng more and more flattened as the line *s* S approaches iptic, until finally it will appear as a straight line when is in the ecliptic, such a star having a merely backıd forward movement.

n all cases this aberrational orbit has the longer axis of the ellipse

parallel to the ecliptic and of the same length for all stars. The value of the minor axis depends on the star's latitude diminishing as we pass from the pole of the ecliptic to the ecliptic itself. The length of the major axis simply expresses the ratio of the velocity of light to the velocity of the earth in its path and is therefore constant. It has been found by careful observation of the stars that this major axis in all cases subtends at the earth an angle of 41″, and half this angle, or 20″·5, is known as the *Constant of Aberration*. Now the relation holds that

$$\tan 20''\cdot 5 = \frac{\text{velocity of earth in its path}}{\text{velocity of light}}.$$

For this small angle the tangent may be regarded as equal to the angle itself, expressed in circular measure. Hence $20''\cdot 5 = \frac{206265\,v}{\mathrm{V}}$, when v is the orbital velocity of the earth and V the velocity of light. The velocity of light, V, has been very accurately measured by a process invented by Foucault (see par. 55) which measured the time taken by light to move from one station to another and back, the distance between the two being known. Both stations were on the earth, and so this method is entirely terrestrial, depending on no celestial measurements. By this means it was found that the velocity of light was 186,330 miles per second. Applying this to the case of aberration we get the velocity of the earth in its path from the equation

$$v = \frac{20\cdot 5 \times 186{,}330}{206{,}265} = 18\cdot 5 \text{ miles per second, nearly.}$$

(This velocity varies in different parts of the orbit, but the average velocity is easily obtained.) Then knowing that the earth takes 365·256 days for a complete revolution in its path, and knowing the average velocity in that path, we can find the length of it by multiplying 18·5 by the number of seconds in a sidereal year. It is then a simple geometrical problem to find the average distance of the sun. Looking on the earth's orbit as a circle, the problem is only to find the radius of a circle knowing the circumference. This is done by dividing the circumference by 2π. The reader is left to work out the result from what has been given. In reality the ellipticity of the orbit is taken into account, and the average distance correctly estimated. By this method an average distance of 92,975,500 miles has been found. This result agrees very closely with the distance deduced by Dr. Gill from his observations on the parallax of Mars.

204. **Distance of Sun.**—Thus four methods of obtaining this most important distance have been indicated.

I. From observations on the parallax of Mars.
II. ,, ,, ,, ,, transits of Venus.
III. ,, ,, ,, ,, constant of aberration of light.
IV. ,, ,, ,, ,, eclipses of Jupiter's satellites (par. 105).

It should be noticed that the last two methods do not require any knowledge of the size of the earth.

Other methods are employed, but need not be dilated on

here. For the present we may then take, as a near approach to the truth, that the average solar distance is 93,000,000 miles, with a possible error of less than 100,000. In older astronomies the sun's distance was given as 95,000,000 miles. This was calculated from a solar parallax of $8''\cdot 57$. It will be noticed that more accurate measurement has raised this value to $8''\cdot 8$ and the reader will now understand that an increase in parallax involves a decrease in distance. A difference in parallax of one-hundredth of a second, $0''\cdot 01$, corresponds to a difference in the sun's distance of more than 100,000 miles.

205. **Distance of Planets from the Sun.**—Having once accurately determined the distance from the earth to the sun we shall find this a convenient base-line from which to deduce other distances. So important is it that it is known as the *astronomical unit.* From Kepler's third law, so often referred to, we can deduce the ratios of the distances of different planets from the sun when once the ratio of their periodic times is accurately observed. This has already been sufficiently illustrated in pars. 26 and 201. A table will be found in the appendix giving the results as obtained for each of the planets. Of course the alteration in the value of the earth's distance from the sun just referred to has caused a corresponding alteration in the values given in older astronomies of the sizes of the other planetary orbits.

206. **Sizes of the Planets.**—Having obtained the distance of a planet, it only remains to measure, with our micrometer and telescope, the angular magnitude of the planet's disc, and then from the ratio, sin ($\frac{1}{2}$ angular magnitude of planet) $= \dfrac{\text{radius in miles of planet}}{\text{distance in miles of planet from the earth}}$, we get the required radius of the planet. By this method were obtained the diameters of the planets given in the table in par. 21. See also par. 3.

207. **Distance of the Stars.**—Seeing that the parallax of the sun, as viewed from two stations on the earth's surface, is excessively small, it will be understood that the parallax of the fixed stars, which are so much more distant, is still very much smaller. But the earth moves round the sun, and the two opposite points in its orbit are distant 186,000,000 miles. Let us then observe a star's position at one point in the earth's orbit, and six months later, when we are 186,000,000 miles

away from the first place, let us again observe the same star's position. It would be expected that this considerable change of point of observation must have caused a considerable apparent angular displacement of the star in the background of the heavens—in other words, the star should have a considerable parallax. As this parallax is due to the change in position of the earth during its yearly revolution, it is called ***annual parallax***, to distinguish it from the *diurnal parallax* explained in par. 197, and illustrated in fig. 141. As the earth's equatorial radius subtends no appreciable angle at the fixed stars at any altitude during any part of the day, the fixed stars have no diurnal parallax. Even the annual parallax for any star is so small as long to have escaped notice, and, for most stars, it is still inappreciable. Let us see what this means. No annual parallax is equivalent to saying that from the star our base-line of 186,000,000 miles must appear as a point. The star then must be at an infinite distance, or, at any rate, the parallax is so small that the star's distance is immensely greater than our base-line of 186,000,000 miles. Small as it is, nevertheless, it has been measured in certain cases. Direct attempts were found to be almost useless. For, after making all possible corrections, it was found that the changing seasons and temperatures affected the instruments too much to allow any reliance on their indications for such a minute angle. A method of differences (*the differential method*) was, however, more easily applied. Some star, suspected to be nearer than usual from its large proper motion or brightness was chosen. Most accurate measurements of its angular distances from very faint or small stars close to it were taken throughout the course of the year. These small stars are probably at distances very much greater than that of the bright star. This bright or large star and its comparison stars are all affected by the same errors of observation. If, then, there is any *relative change of position*, it can only be produced by the parallax of the large star being greater than that of the comparison stars. In this way measurements have been made of the parallaxes of certain stars, and on the assumption that the small comparison stars have no appreciable parallax from their

mmensely greater distance, an estimate is formed of the distance of the large star. We give a few of the most satisfactory results n a table. It is to be understood that the parallax we give in the table is half that spoken of above, being the amount due to change of observation from the earth to the sun. Therefore, *Annual Parallax means the angle subtended at the star by a radius of the earth's orbit*, a distance of 93,000,000 miles. Since a second of the angle is $\frac{1}{206265}$ part of a radian (par. 3), a star which has a parallax of 1″ will be at a distance 206,265 times this base-line of 93,000,000 miles, a base-line known as the *astronomical unit.* No star has been found to have a parallax as much as 1″, so that no star is so near as the distance just mentioned. For any star the distance will be given by the formula $\frac{206265\,R}{p''}$, R being the astronomical unit or the radius of the earth's orbit, and p the parallax in seconds. This astronomical unit, the distance of the sun from the earth, is not deemed large enough to express stellar distances, and it has been thought better to adopt as a unit for this purpose the distance through which light passes in a year, which is about 63,000 times greater than the ordinary astronomical unit. *Light-vear* is the term used to designate the unit of stellar distances, and it expresses the distance through which light travels in one year. A parallax of 1″ corresponds to a distance of 3·262 light-years, so that for any star its distance in light-years will be given by the formula $\frac{3\cdot262}{p''}$.

Stellar Parallaxes and Distances.

Name of Star	Magnitude	Annual Parallax	Distance in Astronomical Units	Distance in Light-Years
α Centauri	1	0″·75	275,000	4·35
61 Cygni	5½	0″·44	469,000	7·41
Sirius	1	0″·38	543,000	8·58
Lacaille 9,352	7½	0″·29	711,000	11·24
Lalande 21,258	8½	0″·26	793,000	12·50
O² Eridani	4½	0″·19	1,086,000	17·1
α Lyræ (Vega)	1	0″·16	1,289,000	20·4
β Cassiopeiæ	2	0″·16	1,289,000	20·4
α Aurigæ (Capella)	1	0″·11	1,875,000	29·6
Pole Star	2	0″·089	2,318,000	36·2
Groombridge 1,830	6½	0″·07	2,946,000	46·6
85 Pegasi	6	0″·05	4,125,000	65·2

It must be understood that the errors in the above may be considerable, though some of the values are probably close approximations to the truth. We see that the nearest fixed star is so remote that it takes light more than four years to reach us, and if the star were suddenly extinguished we should continue to receive its light for four years more. This corresponds to a distance of about 275,000 times the astronomical unit (or the earth's distance from the sun)—nearly 25,000,000,000,000 miles; whilst it has been conjectured that some of the more distant stars are sc far off that their light takes centuries or even thousands of years to reach us, and a still bolder speculation suggests that the light from some stars has not yet reached us.

The parallactic orbit of a star when sensible is similar in *form* to its aberrational orbit, but of much less extent. The aberrational orbit is of the same size for every star, its semi-major axis always being 20″·5 (Nyren's value is 20″·492); while the parallactic orbit varies in size with the distance of the star, and its semi-major axis is in all cases less than 1″. Moreover, the displacement due to aberration is always in the direction of the tangent to the earth's orbit (this direction of the earth's motion in its orbit is called the *earth's way*); while the displacement due to parallax slightly shifts the star towards the sun. In other words, the star is always 90° in front of the earth in its aberrational orbit, but always opposite to the earth in its parallactic orbit.

It will occur to the reader that the displacements of a star due to aberration and parallax are convincing *proofs* of the earth's revolution in an orbit round the sun.

208. **Proper Motion of the Stars.**—We have hitherto spoken of the stars as fixed, because, as compared with the sun, moon, and planets, they keep their relative positions unchanged. Their apparent daily path in the sky, due to the rotation of the earth, and the progressive changes in the position of the stars at the same hour of the night due to the earth's revolution round the sun, cause no change in their relative positions nor in the shape of the constellations; while the small apparent changes of position, due to precession and nutation, have been shown to be caused by alterations in the directions of the earth's axis (par. 180). Aberration also causes a motion, but only an apparent one (par. 203). But, apart from these common and apparent motions, some stars have a real or proper motion, which slightly displaces them with reference to the stars near them. This is not a periodical motion, such as could be produced by annual parallax, but a small progressive motion across the line of sight from year to year—an angular displacement which produces a change of the point at which a star is seen on the celestial sphere when observations are made at wide

intervals of time. As a result of this proper motion, there is a slow but constant change in the figure of some of the constellations; a change, however, which requires, in most cases, a thousand or more years to become visible to the naked eye. The annual angular amount of this telescopic proper motion for several stars is annexed.

1,830 Groombridge,	7″·05	O^2 Eridani,	4″·1
9,352 Lacaille,	6″·96	α Centauri,	3″·7
61 Cygni	5″·2	Arcturus,	2″·2
21,258 Lalande,	4″·4	Sirius	1″·2

Knowing the distance of a star, the annual proper motion in arc can be converted into linear measure. Thus it has been found that Arcturus is moving at some 54 miles a second, and the star Groombridge 1,830 at the enormous rate of 200 miles a second. It is reasonable to assume that the brighter stars are, as a *class*, nearer, and as a consequence they show, on the *average*, the greatest proper motion. But this is only true generally, for several fainter stars show a greater proper motion than any bright ones, and the table in par. 207 shows, for the few results there given, that stellar brightness has nothing to do with remoteness in individual cases.

209. **Motion of Stars in the Line of Sight.**—Besides the proper motion of stars, which causes the displacement sideways when referred to near stars, it has been found that some stars show a motion to or from the earth along the line of sight. This has been proved by means of the spectroscope. According to Doppler's principle, already explained, the lines in the spectrum of a star approaching the earth will be towards the blue, while in one receding the displacement will be effected towards the red. Such displacement of the Hγ line of hydrogen has been observed in several cases. The stellar spectra are compared with those of hydrogen or sodium, either by direct eye-observations of the two spectra simultaneously, or by photographing both spectra on the same plate and measuring the displacement afterwards. As a result of such spectroscopic measurements it was found on one occasion that Arcturus and α Lyræ were approaching us at the rate of about fifty miles a second, while Sirius and α Orionis are receding from us at the rate of about twenty miles a second.[1] Further, five of the stars in the

[1] As an example of a measurement of motion in the line of sight, it may be stated that in one observation of Sirius the F-line of hydrogen was shifted towards the red, that is, increased in wave-length by 0·109

constellation of the Great Bear or Plough are found to be moving in the same direction, while two of the stars—the brightest of the pointers and the star at the end of the handle—are moving in an almost opposite direction. Other groups of stars appear to have a community of motion different from those around them.

210. **Causes of Proper Motion.**—The proper motions of the stars above described consist partly of a real independent motion of their own through space, but partly also of an apparent motion caused by a motion of the whole solar system through space. The sun, itself a star, is found to have a proper motion, moving with his retinue of planets, including the earth, towards a point called the *apex of the sun's way*, in the constellation Hercules. This is shown by the fact that the stars in the part of the heavens towards which the sun is moving appear on the whole to be opening out or separating from each other, while in the opposite part of the sky they seem to be closing up. Such an effect would be observed were the reader to walk along a road with rows of trees planted on each side.

211. **Summary of Corrections.**—We may here repeat all the corrections that are necessary to be made in astronomical observations after the instrumental and clock errors have been carefully obviated or allowed for.

1. Refraction 2. Diurnal or Geocentric Parallax.	period 1 day .	Depend on the place of observation.
3. Aberration	period 1 year .	Depend on the time of observation, the positions of the sun and of the moon's nodes.
4. Precession	period 25,800 years	
5. Nutation	period 19 years	

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millionth of a millimetre. Now the velocity with which two bodies move away from each other bears the same proportion to the velocity of light that the observed difference of wave-length bears to the particular ray. The wave-length of F is 486 millionths of a millimetre (par. 72).

Hence

$$486 : 0{\cdot}109 :: 186{,}330 : x = 41{\cdot}7$$

that is, there was at this time a motion of recession between Sirius and the Earth of 41·7 miles per second.

CHAPTER XIII.

GRAVITATION AND CELESTIAL MASSES.

212. **Explanation of Terms.**—Before entering on this subject it will be necessary to bring forward and amplify some of our elementary definitions, and show how they are applied for astronomical purposes.

The velocity of a body is the rate of change of its position, and is measured by the space the body passes over in some fixed time.

Uniform velocity.—A body is said to possess uniform velocity when the successive spaces passed over in equal intervals of time are equal, however small the intervals of time may be.

A unit velocity is the velocity a body possesses when it passes over unit space in unit time (say a velocity of one foot per second, or one c.m. per second, according to the standard of measurement).

Acceleration is the rate of change of velocity, and is measured by the amount of velocity added in some fixed time.

Uniform acceleration.—A body is said to possess a uniform acceleration when the successive increments of velocity added in equal intervals of time are equal (however small those intervals of time may be).

Unit acceleration is the acceleration a body possesses when it gains unit velocity in unit time (say, gains a velocity of one foot per second, or one c.m. per second, according to our standard of measurement).

Mass.—The term mass has been defined in the 'Elementary Physiography' as being the quantity of matter contained in a body. This definition must now be supplemented by taking into consideration the effect of forces on different masses.

Force we have defined to be any cause which changes, or tends to change, a body's state of rest or motion. If a force, which we may call unit force, act on some body originally at rest, and which contains unit mass, for the space of one second

of time, it will impart to it a velocity which we call unit velocity. If our unit force continue to act on the unit mass for another second, it will add to its already acquired unit velocity another unit velocity; leaving it at the end of the two seconds with two units of velocity. Similarly, if the force acted for a third second it would leave the body at the end of three seconds with three units of velocity, and so on. The force during each second that it acts adds unit velocity to the body. In fact, one unit force acting on unit mass produces unit acceleration. Then, of course, two unit forces acting on two unit masses side by side, as it were, would also produce on each or on the two together unit acceleration. We may now see that two unit forces acting on one unit mass would produce two units of acceleration, three unit forces produce three units of acceleration, and so on.

Or, again, one unit force acting on two unit masses would produce only $\frac{1}{2}$ of a unit of acceleration, one unit force on three unit masses produces $\frac{1}{3}$ of unit acceleration, and so on.

We now see the connection between force, mass, and acceleration. Thus, applying the above numerical examples, we have :

(Unit force)	gives in	(unit mass)	(unit acceleration)
(2 units ,,)	,,	(2 units mass)	(unit ,,)
(2 units ,,)	,,	(unit mass)	(2 units ,,)
(3 units ,,)	,,	(3 units mass)	(unit ,,)
(3 units ,,)	,,	(unit mass)	(3 units ,,)
(unit ,,)	,,	(3 units mass)	($\frac{1}{3}$ unit ,,)

In fact the law is :

Force varies as the product of the mass into acceleration, and this at once gives us a fuller appreciation of the meaning of the term mass and of estimating different masses ; for if the same force act on two different masses it will produce different accelerations, and the ratio of the acceleration is the inverse ratio of the masses. Or, again, if the accelerations produced on the two masses be equal, then the ratio of the masses is the direct ratio of the forces acting on them. The latter case occurs to us at once in connection with bodies on the surface of the earth. All bodies let fall towards the earth fall with appreciably the same acceleration. Therefore their masses must be proportional to the forces which make them fall. These forces we call their weights. Hence we can say that on the earth's surface the *mass of a body is proportional to its weight*.

213. **Gravitation.**—The fact that a body has weight on the earth's surface is explained by saying that the earth has an ***attraction*** for the body and pulls it towards its own centre.

But this is only a particular case of a universal attraction which every body has for every other body in the universe.

Newton wrote his great work the 'Principia' to show that Kepler's laws of planetary motion could all be explained on the assumption that there was an attraction between the sun and the planet which varied directly as the product of the mass of sun and planet, and inversely as the square of the distance between them. But this was still not the complete truth, for he applied it to the case of falling bodies on the earth's surface, and to the retention of the moon in its orbit round the earth, and, in fact, he formulated his theory of *Universal Gravitation* 'that every particle of matter in the universe attracts every other particle, with a force whose direction is that of the line joining the two, and whose magnitude is directly as the product of their masses, and inversely as the square of their distances from each other.'

This theory receives such enormous authority from its power of explaining every known motion of celestial bodies, which can be observed with the utmost refinements of astronomical instruments, as to be commonly called the Law of Gravitation, and it is the application of this Law of Gravitation which enables us to calculate the masses of celestial bodies, or rather the ratio of their masses to that of the earth.

Let us see how this Law of Gravitation will help us.

214. **Mass of the Sun.**—If we could place a body at the same distance in succession from the sun and earth it would be attracted towards each with forces directly proportional to their masses. Or, if it fell towards each, it would fall with accelerations proportional to the masses of sun and earth. This acceleration could be measured by the space fallen through in the first second, and, if the above experiment were carried out, the body would fall towards the sun in one second through a space about 330,000 times greater than it would towards the earth, showing the sun's mass to be 330,000 times greater than that of the earth. But we cannot carry out the above experiment; nor is it necessary that we should, for two reasons. First, we need not place the body at equal distances from the sun and earth, but make allowance for variation in

distances by the law of inverse squares. Secondly, we need not even employ the same body in the two cases, for the acceleration will be always the same, the larger mass being acted on by just as much larger a force. Just as in the case of bodies at the surface of the earth; whatever their masses or weights, they all fall with exactly equal accelerations (at the same place). Bearing in mind the two points above explained, we are now in a position to estimate the ratio of the masses of sun and earth.

But where are our two falling bodies? They are the moon and earth. The moon continually falls towards the earth because of the latter's attraction, and the earth towards the sun because of the sun's attraction. A diagram will make this clear. The moon's orbit may be fairly correctly represented by the circle M Q T N, round E, the earth, at the centre of the circle.

M is the position of the moon at any time, moving in the direction M P. If no force acted, it would move in a straight line M P, and M P is supposed to represent the small distance it would pass over in one second. But the earth compels it to move along M Q, the arc of the circle which it describes in one second, P Q being practically parallel to M E; so that the earth, as it were, has made the moon, in one second, fall through the distance P Q, away from the path it would have pursued if not attracted towards the earth. It is in this sense that we say the moon falls towards the earth, though not necessarily getting nearer.

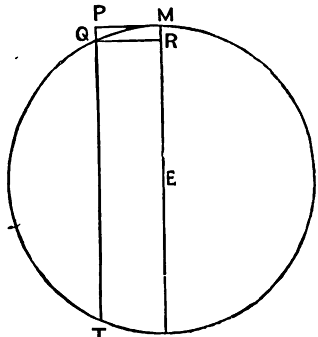


FIG. 148.

The straight line P Q is produced to cut the circle in T, and Q R is drawn parallel to M P.

Then, by Euclid III. 36, since P M is a tangent, and P Q T a chord of the circle, $\therefore$ $PM^2 = PQ.\ PT$.

For all practical purposes the arc M Q is so small compared to the whole circumference, that we can assume the tangent P M = the arc M Q, and the chord P T = the diameter M N.

Then we have $(MQ)^2 = PQ.\ MN$, or $= MR.\ MN$.

M Q we know, for it is the distance traversed by the moon in its orbit during one second.

The whole path M Q T N M = 3·14159 × twice moon's distance from earth = 1,508,000 miles nearly.

The time required to travel this distance = 27·32 days, $\therefore$ distance travelled in one second is about 3343⅓ feet; M N is the diameter of the moon's orbit = 480,000 × 1760 × 3 feet nearly. $\therefore$ $PQ = \frac{MQ^2}{MN} =$

$\frac{(3343\frac{1}{3})^2}{480,000 \times 1760 \times 3}$ feet = ·053 inches, and MR = PQ = ·053 inch.

That is, the moon in each second falls towards the earth through a distance of about ·053 inch.

In exactly the same manner we calculate that the *earth* in each second falls towards the *sun* through a distance of about ·115 inch.

But the sun is 386 times farther off than the moon ; applying then the law of inverse squares we have :—sun's mass : earth's mass

$$= \frac{\text{earth's fall towards sun}}{1^2} : \frac{\text{moon's fall towards earth}}{(386)^2}$$

$$= \frac{\cdot 115}{1} : \frac{\cdot 053}{(386)^2}$$

$$= 323,000 : 1$$

Thus the sun's mass is about 323,000 times greater than that of the earth.

215. **Mass of Planets with Satellites.**—The method just explained may be used to find the mass of any planet with a satellite, or rather its ratio to the mass of the sun and thence to the mass of the earth. The ratio can be put in the simple form

$$(M + m) : (m + m') = (a')^3 t^2 : a^3 (t')^2,$$

where a stands for the semi-axis major of the planet's orbit round the sun, and t for its periodic time, and a' and t' the same quantities for the satellite's orbit round the planet. M is the mass of the sun, m of the planet, and m' of the satellite ; and these two last may be found from the equation when the values of the others are known.

(It may be noticed that the above formula is a modification of Kepler's Third Law corrected by taking into account the masses of the attracting bodies. The amended law is thus expressed by Clerk Maxwell in 'Matter and Motion': 'The cubes of the mean distances are as the squares of the times multiplied into the sum of the masses of the sun and the planet.')

Jupiter's mass.—By this method, taking an average from the results deduced from each of the four moons of Jupiter, its mass has been found to be $\frac{1}{1047}$ of that of the sun, or 310 times that of the earth.

Saturn's mass has been obtained from observations on its two largest satellites, with the result that it is $\frac{1}{3500}$ that of the sun, or 93 times that of the earth.

Uranus' mass deduced from its four satellites is $\frac{1}{22600}$ that of the sun, or 14 times that of the earth.

Neptune's mass, deduced from its only satellite, is $\frac{1}{19380}$ that of the sun, or 17 times that of the earth.

Mars' mass was uncertain until the recent discovery of its two small satellites, when observations of them gave us the planet's mass as $\frac{1}{3100000}$ that of the sun, or $\frac{1}{10}$ that of the earth.

216. **Masses of Planets without Satellites.**—For the two planets Venus and Mercury another and less accurate method has to be employed. This depends on somewhat elaborate calculations of the effect of one planet by its attraction causing perturbations or slight changes in the path of another. The perturbations will depend on the mass and nearness of the disturbing body, so that in the case of Mercury the perturbations will be caused mainly by Venus and the Earth, whilst those of Venus will be caused mainly by the Earth and Mercury. A true path for Mercury round the sun without perturbations is calculated. Its real path is carefully observed. The differences give an indication of the perturbing effects of Venus and the earth. In a similar way the differences in the real and true paths of Venus indicate the perturbing effects of the earth and Mercury.

So that finally a series of equations can be got from which are deduced the masses of Venus and Mercury as compared to the sun or earth. Venus is found to have a mass $\frac{4}{5}$, and Mercury $\frac{1}{16}$ that of the earth; though the last is so difficult to determine that a more recent and probably more accurate method makes it as much as $\frac{1}{8}$.

217. **Other Methods specially applicable to Jupiter.**—Jupiter has so large a mass, more than twice the sum of the masses of all the other planets, that it makes itself felt notably in the solar system. Particularly is this the case with any comets which perchance come near it in their eccentric orbits. Its attraction in this case is so powerful as completely to change the character of their orbits. For example, the comet of 1769 approaching near Jupiter was made to give up its long-period orbit and take a short-period one of $5\frac{2}{3}$ years. But it was not again seen in 1776, and in 1779 it was proved to have got quite close to Jupiter, mixed up with its satellites, and so thrown out of its orbit as to be sent off as a parabola away from the solar system, never to return. From observations on the perturbations of the paths of comets, a mass has been calculated for Jupiter closely agreeing with that already given. Again, some of the asteroids revolving between Mars and Jupiter have perturbations given them by their enormous neighbour Jupiter, which again serve as basis for a calculation of

his mass. The same applies to Saturn's perturbations by Jupiter, but not so accurately, because of the long period of time necessary for full observation; and, as an indication of the accuracy of observations, it may be stated that all these methods lead to practically the same mass for Jupiter.

For convenience we repeat the masses of the planets as given by M. Tisserand, the mass of the earth being the unit.

Mercury $\frac{1}{16}$? $\frac{1}{8}$	Jupiter 310
Venus $\frac{4}{5}$	Saturn 93
Earth 1	Uranus 14
Mars $\frac{1}{10}$	Neptune 17

If we take the weight of the earth as 6,000,000,000,000,000,000,000 tons, the weights of the planets can easily be calculated. The *density* of a planet compared to that of the earth is determined by dividing its mass by its volume.

218. **Masses of Satellites.—The mass of the Moon** can be determined by three or four methods, but, strange to say, not so accurately as in the case of some of the planets, though it is so much nearer. We shall describe one of these methods. Though we say that it is the earth which revolves in an orbit round the sun, it is really the common centre of gravity of the earth and moon that so revolves. This is at such a short distance from the centre of the earth that but little error is usually introduced. However, that little error is now of importance for our present investigation. The moon and the earth revolve monthly round their common centre of gravity, which centre moves round the sun; consequently the earth is sometimes in advance of its mean place in longitude by the radius of this small monthly orbit, and sometimes as much behind the mean place. At new and full moon, when the earth, moon, their common centre of gravity, and the sun, are all near the same straight line, the earth occupies its mean position. At the two quadratures of the moon, the line joining the earth and moon is at right angles to the line joining the earth and sun. Hence at quadratures the earth is farthest from its mean position. But we do not recognise these displacements of the earth in longitude, except by the apparent motion of the sun in the ecliptic, which is correspondingly affected. We are then to look out for an inequality in the sun's motion in the ecliptic which shall be greatest during the quadratures of the moon and be zero at new and full moon. This inequality has been found and its maximum measured with results which give as a

mean $6''\cdot3$. Assuming a mean equatorial horizontal solar parallax of $8''\cdot8$, we find that the earth's centre is distant from the centre of gravity of earth and moon by an amount which is $\frac{63}{88}$ of the earth's equatorial radius, i.e. about 2,830 miles. This distance is about $\frac{1}{81}$ of the distance from the earth to the moon. Therefore

Moon's mass : earth's mass = 1 : 81

The moon's mass is, then, about $\frac{1}{81}$ that of the earth.

The Satellites of Jupiter and of Saturn have had their masses calculated from their mutual perturbations on one another.

219. **Masses of some Stars.**—Certain stars have companions, and the two revolve round their common centre of gravity. But to simplify the problem of their motion the smaller is considered as revolving round the principal member of the pair, whose mass is considered as increased by the mass of the satellite, which latter is given an orbit the mean of the two orbits. The fall of the secondary star to its primary star in one second is reckoned and compared with what it would be at the earth's distance from the sun. Then the ratio of the sum of the masses of the two stars to that of the sun is the ratio of the two falls. This, of course, necessitates a knowledge of the star's distance. For example, the double star α Centauri is found to have the sum of its masses 1·8 times, and γ Cassiopeiæ about 8·3 times that of the sun. The case of Sirius was interesting because, from its irregular motion, a mass and orbit for an unknown companion were calculated, and these were found to agree fairly with those afterwards really observed on the telescopic discovery of the small companion.

CHAPTER XIV.

STARS AND NEBULÆ.

220. We have already spoken of the number and magnitude of the stars, the term 'magnitude' referring simply to their brightness. Each descent in stellar magnitude represents a falling off in light in the proportion of $2\frac{1}{2}$ to 1. For the sake of great exactness the brightness of a star is often expressed to the nearest tenth of a magnitude by means of decimals. Thus we have stars with a magnitude of 2·5, 2·6, and so on. As we have seen, the nearest fixed star, so far as astronomers have yet ascertained, is about 275,000 times more distant from us than the sun. Seen from this star—α Centauri—the sun would only be about as bright as the pole star, while the earth and the

other planets of the solar system would be entirely invisible in the most powerful telescope yet constructed. Further evidence that the solar system is a mere isolated group in space is furnished by the almost undisturbed motions of the outmost planets Uranus and Neptune; for any large body like the sun within a thousand times the radius of the earth's annual orbit would manifest its presence by perturbations of these planets.

221. **Nature of Stars.**—Many of the stars are in reality suns—that is, bodies comparable in size and physical condition to our sun, which, as we have seen, is in all probability a mass of intensely heated incandescent vapour sheathed in photospheric clouds. Some of the stars, as shown by their spectra, are far hotter than our sun; others have become cooler. According to Professor Lockyer, another part of the vast number of stars are not yet constituted like the sun, but are simply collections of meteorites, the particles of which are at a greater or less distance apart. Indeed, Professor Lockyer regards all the luminous bodies in the universe as consisting of swarms of meteorites, or masses of meteoric vapour in various stages of condensation, their luminosity being due to the heat produced by collisions and condensation in the swarms. Beginning with the nebulæ, which he believes to consist of meteoric dust-particles widely separated, a clashing among the particles, or condensation produced by gravitation, results in an increase of heat and brightness as the swarm condenses and the number of collisions increases.

We thus arrive at what he terms the first group of 'stars,' really systems of meteorites somewhat hotter and closer than those in nebulæ and forming but one group with these cloud-like patches. In this group comets are also included, as they are supposed to be patches of meteoric nebulæ drawn into the solar system. As a swarm goes on condensing the number of collisions increases, the temperature rises and more light is radiated, and we get another group of 'stars.' A continual fall of meteoric matter towards the condensing centre eventually reduces the meteorites to a mass of vapour, and a true star is produced. The hottest stage of this vapour is represented by such stars as Sirius and α Lyræ. After this the loss of heat by radiation exceeds that produced by the fall of meteoric material and the condensation of the gaseous mass, and cooling sets in. Stars near this first stage of cooling consist of a densely gaseous, liquid, or solid nucleus surrounded by an atmosphere of absorbing vapours, the composition of which varies with the degree of cooling. Amongst such cooling stars may be placed the *sun, Capella,* and Pollux.

A later stage of cooling is represented by certain stars of a deep red colour. In these the central mass of meteoric vapour is probably so far condensed as to become liquid, and the body is surrounded by an absorbing atmosphere largely composed of carbon vapour. Finally, the body so far decreases in temperature as to be no longer self-luminous. To illustrate this classification of the heavenly bodies, which is really based on differences produced by changes of temperature as indicated by the various spectra, Professor Lockyer gives a temperature curve somewhat like the following to illustrate these changes in a graphic form.

Starting with groups of very sparse meteorites, we have in group I. nebulæ and 'stars' with bright lines indicating radiation at low temperatures. As we ascend the left-hand side of the curve, we come to group II. consisting of 'stars' where the meteorites are closer together than in the preceding, and where they are surrounded by vapours driven off by the increasing number of collisions. Their spectra are said to indicate the radiation of carbon vapour and the absorption of magnesium, manganese, lead, and iron. Many of the bodies called *variable stars* belong to this class, as do also the so-called *new stars.*

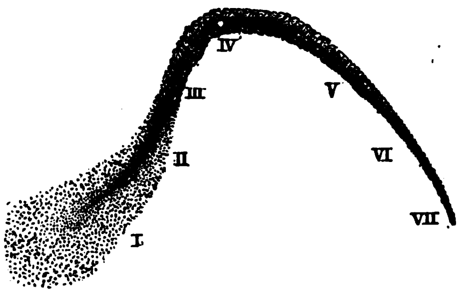


FIG. 149.—Lockyer's Temperature Curve.

Increase of heat through increase of condensation and collisions now brings us to group III., where the meteorites have been reduced to vapour and the spectrum shows line-absorption of various metals. At the top of the curve we have the vapour in its hottest condition, and the spectrum shows the line-absorption of hydrogen. The bodies in this group IV. are coherent globes of gas at a far higher temperature than our sun. As we descend the right-hand side of the curve each step represents a decline in heat. Some distance down the curve we have group V., a class of bodies in which the meteoric vapour is cooling and the spectrum of which is marked by numerous fine absorption-lines like those in the solar spectrum. The substances existing in the atmosphere of these stars are nearly the same as those existing in meteorites, for a mixture of meteorites volatilised in the electric arc furnishes a spectrum of bright lines corresponding almost perfectly with the dark lines of the solar spectrum. Group VI. is formed of stars that have cooled still further, and the spectrum of which indicates an absorbing atmosphere of carbon in some form or other. A final class forms group VII. and consists of cold bodies like most of the planets, the moon, and the companion of Sirius and Algol.

The various groups above indicated are not to be supposed to be sharply marked off from one another. There is a gradual passage of one class into the other, group II., for example, having been divided into fifteen species.

222. Stellar Spectra.—Spectrum analysis reveals to us the vapours in the atmospheres of the various stars, and it is evident that the composition of a stellar atmosphere will depend upon the elements constituting the star, and upon the temperature of the mass within the atmosphere. The physical condition of this atmosphere may also be fairly well deduced from the indications of its spectrum. There appears to be little doubt that the substances composing the heavenly bodies are the same, the differences in stellar spectra being merely due to differences in the 'age' of each body; that is, to difference of temperature. Secchi divided the spectra of the stars into four classes or types. The first type includes the white and bluish-white stars like Sirius, Vega, Regulus, Rigel, &c. The spectrum of these stars is composed of all colours, and is sometimes crossed by a number of fine dark faint lines, but always by four strong dark lines, one in the red, one in the greenish-blue, and two in the violet. All these four lines are due to hydrogen, for they are in exact correspondence with the four bright lines seen in the spectrum of hydrogen examined by means of a

FIG. 150.—Spectrum of Sirius.

Geissler or Plücker's tube. In the brightest stars of this class, a faint line appears to coincide with the sodium line D, and one or two faint lines belong to iron and magnesium.

Secchi's second type of stars includes most of the yellow stars like Capella, Pollux, α Bootis, &c. Their spectrum is substantially the same as that of the sun, and this leads to the conclusion that their atmospheres are very similar to that of the sun in chemical and physical constitution. In some cases, the lines of stars of this type are very fine, but in all cases the lines are most strongly marked towards the blue end of the spectrum.

The third type includes most of the red and variable stars, and is characterised by dark bands as well as lines. Fig. 151 shows the spectra of the stars α Orionis and α Herculis, as examples of this class.

These bands, probably due to metallic fluting absorption, often appear like a row of columns illuminated from the side, and they are sharply defined and darkest towards the violet or more refrangible portion of the spectrum, and fade away towards the red. The fourth type consists of a small number of faint stars having a spectrum of dark carbon bands shaded in the opposite direction and terminating abruptly towards the red, and fading away towards the violet. A spectrum of the fourth type, No. IV. in fig. 151, is furnished by a sixth-magnitude star, 152, Schjellerup's Catalogue.

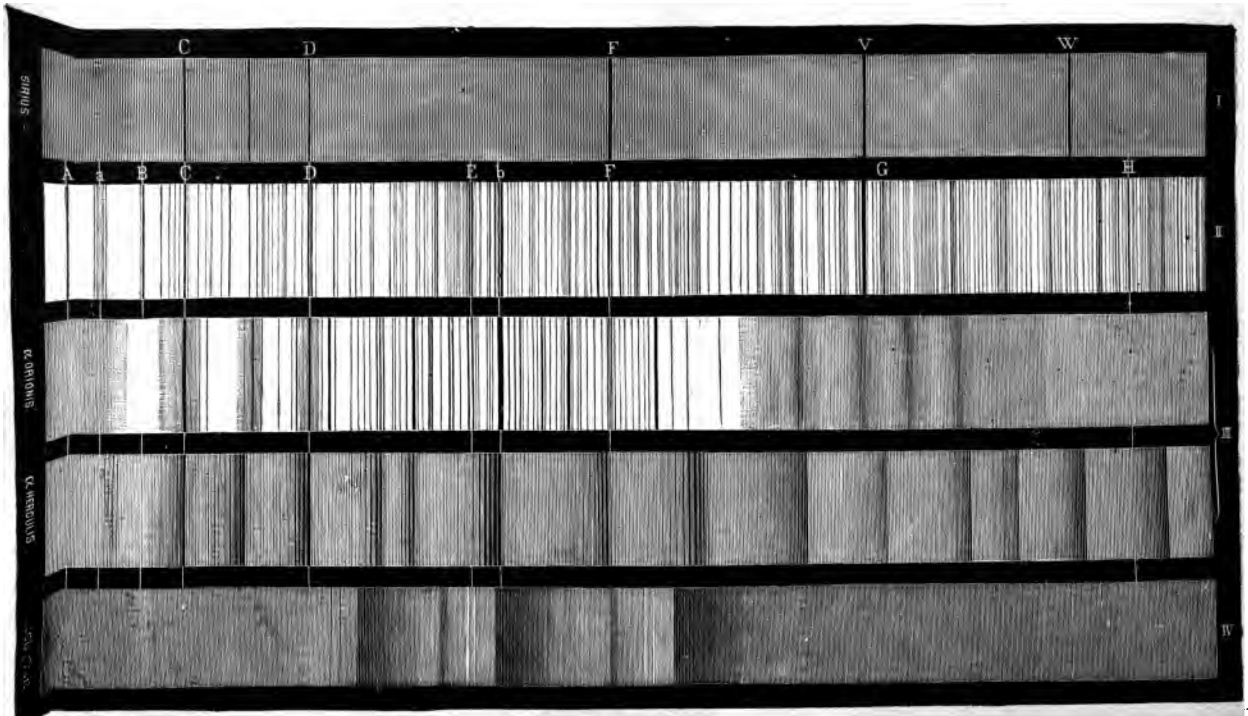


FIG. 151.—Types of Stellar Spectra.

A remarkable exception to Secchi's four types is furnished by a few **stars which furnish a *direct*** spectrum of hydrogen. The most remarkable **of this fifth type is γ Cassiopeiæ**, which furnishes the ***bright*** line Hα (red), **and Hβ (greenish-blue)** in the place of the dark hydrogen lines C and F, **besides sometimes** showing the line of unknown origin, D_3 (*helium*). This **perplexing line is never** seen apart from the bright lines of ignited hydrogen, **and has only been** certainly detected in a few stars, in the hottest region of **the sun, and in some nebulæ.** A few stars show bright lines which are not **those of hydrogen.** The classification of Secchi takes no account of whether **stars at the same mean** temperature are becoming hotter or cooler, and **is certainly, so far,** not so instructive as Lockyer's, set forth in the previous **paragraph. Thus,** part of Secchi's Type II. will be on the ascending side **of the temperature-curve,** and the other part on the descending side, whilst **most of those in the** first type will be at the top of the curve. Lockyer's **classification of stellar spectra is** set forth in the following table [1]:—

		Examples.
Group I.	Nebulæ and 'stars' formed of separate meteorites, the spectra of which show bright radiation lines and flutings.	β Lyræ and γ Cassiopeiæ. Comets at low temperature
Group II.	'Stars' showing radiation of carbon vapour from the interspaces between the meteorites and metallic absorption due to vapours of magnesium, manganese, iron, lead, surrounding the incandescent meteorites.	α Orionis and o Ceti (Mira). Comets at high temperature
Group III.	True stars of increasing temperature with line absorption predominant, the meteorites having all been turned into vapour.	α Tauri, β Ophiuchi, and α Cygni
Group IV.	The hottest stars with spectra characterised by thick strong absorption-lines of hydrogen, while the metallic lines are thin and faint.	α Lyræ (Vega) and Sirius
Group V.	Stars whose temperature is decreasing, and whose spectra show numerous fine absorption lines.	Sun, Capella, and Pollux
Group VI.	Stars of a deep red tint, of lower temperature than the preceding, the vapour produced from the meteorites having become greatly condensed—carbon absorption predominant.	152 Schjellerup & 26 Pickering

223. Variable Stars.—Some stars undergo a change of brightness, the **variation being usually regular** and periodic. The variation is measured **by the different** magnitudes of the stars at different times, and the period of **variability is** the time that elapses between two successive maximum magnitudes. **Many** variables belong to Group II., and show the bright lines **of hydrogen at** maximum. Among variable stars the following are well known:—

[1] See note, page 331.

Name	Epoch 1880		Range of Variation	Period
	R. A.	Decl.		
				About
η Argus	10 h. 24 m. 25 s.	−59° 3′·1	1 to 7	70 years
R Cygni	19 h. 33 m. 36 s.	+49° 55′·8	8 to 13	425 days
R Leonis	9 h. 41 m. 6 s.	+11° 59′·2	5 to 9	$312\frac{1}{4}$ days
o Ceti (Mira)	2 h. 13 m. 18 s.	−3° 31′·3	1 or 2 to 10	$331\frac{1}{3}$ days
R Lyræ	18 h. 51 m. 41 s.	+43° 47′·5	4·3 to 4·6	46 days
β Lyræ	18 h. 45 m. 39 s.	+33° 15′	3·4 to 4·5	12 d. 22 h.
β Persei (Algol)	3 h. 0 m. 22 s.	+40° 29′·6	2·2 to 3·7	$2\frac{9}{10}$ days
U Cephei	0 h. 52 m. 35 s.	+81° 13′·8	7 to 9	$2\frac{1}{2}$ days
U Ophiuchi	17 h. 10 m. 29 s.	+1° 20′·6	6 to 6′·8	$20\frac{1}{3}$ hours

The first star on the list, η Argus, appears to be a variable of long period. In 1800, it was of the sixth magnitude. It then increased somewhat irregularly till it was nearly as bright as Sirius in 1843. Since then it has decreased more rapidly than it rose, and in 1870 was again of the sixth magnitude. Like some other variable stars, it is situated in the midst of a nebula, and appears to some extent to share in the fluctuations of this body.

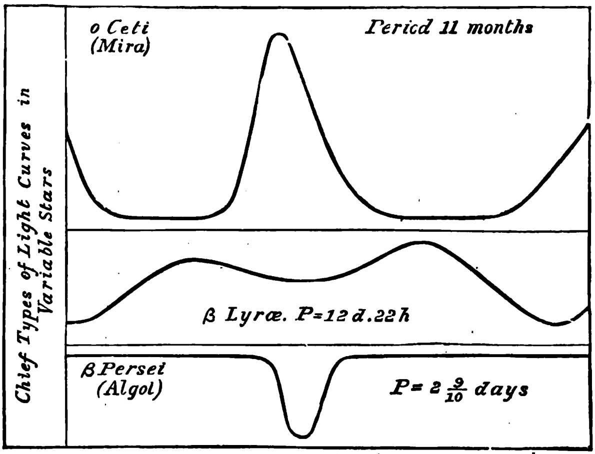


FIG. 152 (after Young).

The star *o* Ceti or Mira is one of the most interesting, and its period from a time of greatest brightness to another maximum of brightness, is eleven months. For about two-thirds of this time it is a faint star below the ninth magnitude; but once in the period its brightness rapidly increases, sometimes up to the second magnitude, sometimes stopping short at the fourth. Remaining at its maximum for ten or twelve days, it then rapidly decreases again. Fig. 152 illustrates its light-curve. Of another type is

β Lyræ which shows two maxima in its short period of thirteen days, as represented in the figure. Another class is represented by β Persei (Algol). Its period is exactly 2 d. 20 h. 48 m. 55 s. During most of the time it shines as a star of the second magnitude, but at the time of change it rapidly falls to the fourth magnitude, remains in this state about twenty minutes, and then in about 3½ hours recovers its original condition. Its light-curve is the opposite of the Mira type. U Cephei is of the Algol type, all its light-changes taking place in about six hours. More than 200 variable stars are given in the catalogue of Mr. Chandler, and the same writer has pointed out certain general relations that appear important. Leaving out the variables of the Algol type, he divides these stars into two classes, those of short period (less than ninety days), and those of long period (more than 120 days.) A curious connection between colour and length of period exists, 'the redder the tint, the longer the period.' Again, the range of variability, speaking generally, increases with the period. Lastly, the light-curve appears to be of a different shape in the two classes.

224. **New or Temporary Stars.**—Eleven well-authenticated cases of new stars or *novas* are recorded. These temporary stars appeared for a few weeks or months, blazing up quite suddenly and then slowly passing away. They are possibly variables of very long periods and of an extreme type. A famous new star was noticed by Tycho Brahe in November 1572, when it was as bright as Jupiter. It soon became so bright as to be visible by day, and then afterwards disappeared, and has not since been seen. Whether it still exists among the small stars in the constellation Cassiopeia, where Tycho observed it, cannot now be determined. A remarkable new star, T Coronæ Borealis, was seen in 1866. From a ninth-magnitude star it suddenly blazed out, between May 10 and 12, as a star of the second magnitude. On the 14th it had fallen to the third magnitude, and at the end of six weeks it had returned to its original faintness. A similarly sudden appearance took place in the constellation Cygnus in 1876, where no star had been previously recorded. The new star rose to the second magnitude in a few hours, remained at its maximum for about two days, and became invisible at the end of a month. It can still be seen as a faint star in a powerful telescope. At its maximum its spectrum was nearly continuous, and showed bright lines of hydrogen and bands of other unknown substances, but the continuous spectrum slowly faded away, and a simple spectrum of bright lines like a nebula was last noticed. Lastly, a most remarkable temporary star appeared in the midst of the great nebula in Andromeda in August 1885. It came out suddenly, reached the seventh magnitude, and passed out of the reach of every telescope in about six months.

225. **Causes of Variability.**—Various explanations have been given of the periodic changes in the brightness of stars, but it is evident that no single explanation will suffice. For temporary stars and stars of the type of Mira (*o* Ceti) Mr. Lockyer has put forth a satisfactory explanation in connection with his meteoric theory of the universe. Temporary stars in his view are due to an encounter between two streams of meteorites in space, during which the collisions between the meteors become so numerous and great that a sudden brightness is developed. 'If the onrush of one stream upon another or a more regular swarm is sudden, we shall have a sudden blaze-out of light; if the on-rushing stream is short, the light will soon die; if it continues for some time, and reduces its quantity, the light will die out gradually. Or, again, such a source of supply may fail by the complete passage of one stream through another.' In this way, the

different kinds of new stars are explained. The changes in the spectrum of these stars appear to support this view, and it is quite certain that no mass so compact as the sun could undergo the sudden increase and diminution of brightness that is observed. In stars like Mira a partially condensed swarm of meteors has revolving round it a smaller swarm (or rather the two revolve round the common centre of gravity), and as this smaller group makes its periastron passage the two swarms clash, more heat is developed, and an increase of luminosity results. See fig. 153. Moreover such an encounter in revolving swarms will produce a *periodic* increase of temperature. The range of variability will vary according to the close-

FIG. 153.

ness with which the central parts of the swarms approach each other at their periastron passage. To stars of the Algol type this collision theory does not apply, as in these we have a sudden and short diminution of brightness. Their variations are generally attributed to the interposition of a dark companion between the star and the earth, so that the light of the star thus suffers a periodical eclipse.[1] The last three stars in the table

[1] Although the distance of Algol is not known, Prof. Vogel has made, from spectroscopic observations, a determination of the orbit of this star. Three photographs, taken before its minimum periods, show the line displaced towards the red end of the spectrum, and three taken after the minima show a displacement towards the violet end, as compared with the lines of the solar spectrum. Careful measurements of these displacements show a motion of approach and recession of the bright star of 27 miles a second. Assuming a circular orbit in a plane passing through the earth, he gives, as the distance of the centres of the two bodies, 3,269,000 miles, and assigns to Algol a diameter of 1,074,000 miles, and to its dark companion a diameter of 840,060 miles.

in par. 223 are of this type. There remain certain irregular variables to which none of the above explanations seem to apply. Possibly the variations of brilliancy in these cases occur in cooling stars, where the surface of a rotating globe is partially obscured by dark masses of scoriæ or crust, sometimes rent by outbursts of luminous matter.

226. **Double and Binary Stars.**—On looking through a telescope at certain stars, which to the naked eye appear single, it is found that in reality they are double stars consisting of a pair of stars close together. Such telescopic double stars consist of two, which are only separated by a few seconds, or even a fraction of a second, of angle. There are known some 2,000 of these double stars, situated in different parts of the sky. Good examples are δ and δ^2 Tauri, two fourth-magnitude stars close together; and α Capricorni, a pair consisting of two very unequal components, whilst ϵ Lyræ is called a 'double-double,' for it consists of one pair very close together, and another pair a little farther off. The important question about such pairs of stars is whether the two have any physical connection by gravitation round each other, or whether they merely seem close together because the one lies behind the other in a straight line from the earth. The former we may call physical doubles or binary stars, and the latter optical doubles. The difference between the two will be found out by accurate and long-continued observations. But we may at once say that probability indicates that there will be few optical doubles, and that although the greater number of the pairs have not yet been proved to have physical connection, in the course of time this connection will be traced. The method of observation is to keep an accurate account, for some years, of the distance between the two stars and of the angle which the line joining them makes with a celestial meridian, called the *position-angle*. The distance between the two is measured by the parallel wire micrometer; and to measure the angle the micrometer has divided circles so that it indicates the angle through which the wires are turned till one of them passes through both stars. The position-angle is really the angle made with the celestial meridian by the line joining the greater star to the smaller, measuring round from the north to the east. If the stars are optically double, these observations will indicate a mere drift of the one star relative to the other—a movement due to their proper motion. If, however, it is a case of a true binary, it will be found that the stars revolve round one another, and that their orbits and periods can be calculated. Of course, it will be a case of both the stars revolving, under gravity, round their common centre of gravity; but in the case where one of the pair is much larger than the other, this will have much the appearance of one star revolving round the other, as a planet does round the sun. Many such orbits have been determined, and their periods extend from 14 years (for δ Equulei) to 1,600 (for ζ Aquarii). But it is to be observed that the observations have not been carried on for a sufficient length of time to make a period of more than 200 years certain. But in course of time, orbits of thousands of years will be clearly established, and most of the doubles will be found to be binaries or real physical doubles. Sirius is a double star of considerable interest. For its orbit was observed and the orbit and position of its companion calculated before the latter was discovered. The companion was first observed in 1862 and was found to have the position and orbit very nearly as indicated by theory.

Figures 154, 155, 156 are illustrations of double stars as seen in a three-inch telescope. 49 Cygni appears as a rather close couple, and the

contrast of colours, as is usually the case, is very beautiful. The star of larger magnitude is always reddish or yellow, and the smaller one green or blue, when the magnitudes differ considerably. 61 Cygni is a wider couple, the pair revolving round their common centre of gravity in about 450 years. The stars described as ϵ^1 and ϵ^2 Lyræ make a double-double, and the figure shows a faint star between the two pairs.

Coloured stars were first prominently noticed in connection with the contrasted colours of binary stars. But among naked-eye stars we have also varieties of colour—stars nearly white like Sirius, yellow stars like Capella, orange or reddish like Arcturus, and pale blue like Vega. Among smaller stars, red, orange, green, and blue are common colours. In η Cassiopeiæ we see a binary where the larger star is nearly white and its companion purple.

FIG. 154.—49 Cygni.

FIG. 155.—61 Cygni.

FIG. 156.—ϵ^1 and ϵ^2 Lyræ.

227. **Distribution of Stars.**—A luminous belt, called the *Galaxy* or *Milky Way*, surrounds the heavens, nearly in a great circle, so as to divide the sky into two portions almost equal. This belt of light is of irregular width and brightness, and is seen in the telescope to be mainly composed of small stars, from the eighth magnitude downwards. It also contains a large number of star-clusters, but very few nebulæ. For about one-third of its way it is divided into two nearly parallel streams. Although the largest stars are scattered somewhat irregularly, the great majority of the stars appear to gather together in and about the Milky Way, and thus indicate to us the direction in which the stellar system has its greatest dimensions. To borrow the words of Professor Newcomb: 'The great mass of the stars which compose the stellar system is spread out on all sides in or near a widely extended plane passing through the Milky Way. In other words the large majority of the stars which we can see with the telescope are connected in a space having the form of a round flat disc, the diameter of which is eight or nine times its thickness. Our sun, with its attendant planets, is situated near the centre of this disc-like space. On each side of the galactic region the stars are more thinly and evenly scattered, and we have a nebular region with few stars but a great number of nebulæ.' In the southern hemisphere are two cloudy oval masses of light like detached portions of the Milky Way. They are called the *Nubecula major* and *Nubecula minor*, and consist of star-clusters and nebulæ.

228. **Nebulæ.**—A large number of cloudy patches of light appear in the sky and are spoken of as *nebulæ* (Lat. *nebula*, mist). More than 10,000 of these bodies have been observed and

their places laid down, but only two of them—the nebula in Andromeda and the Orion nebula—can ever be seen by the naked eye. Many bodies once supposed to be nebulæ were found, with powerful telescopes, to consist of a close cluster of stars, and this led some to suppose that all these cloudy masses would be thus resolved. The spectroscope has, however, disposed of this supposition, for it has clearly shown that there are bodies that cannot be separated into distinct stars, and that the light of many of the nebulæ proceeds mainly from luminous gas. This does not necessarily prove that the nebulæ are mere masses of gas, as is often stated. Mr. Lockyer regards them as consisting of swarms of sparse meteorites at a low temperature, the light proceeding from the glow of the gases between the meteoric particles.

229. Classification of Nebulæ.—The nebulæ are divided into groups based upon their telescopic appearance. Six classes are thus enumerated :—

1. *Irregular Nebulæ.* 2. *Annular or Ring Nebulæ.*
3. *Elliptical Nebulæ.* 4. *Spiral or Whirlpool Nebulæ.*
5. *Planetary Nebulæ.* 6. *Stellar Nebulæ or Nebulous Stars.*

The great nebula of Orion extends over several square degrees, in the constellation of that name, and appears to surround the multiple star Theta (θ). This star lies between κ and ζ (figs. 7 and 8) and forms the middle one of three faint stars known as the sword that hangs from the belt. The nebula sends out streamers in different directions, is of a greenish-white tinge, and seems to undergo changes of shape. The nebulous matter surrounding the stars appears mottled, but the positions of its brightest portions are changing. Fig. 157 is a representation, by Captain Noble, of the Orion nebula as seen in a *small* telescope. The multiple star θ Orionis forms the trapezium of four stars near the centre, and the dark gap leading up to the trapezium is known as 'the fish's mouth.' In a powerful telescope two other faint stars are seen in θ, and a greater extension of nebulous matter appears. Photographs obtained by long exposure show the nebula of still greater extent. Magnificent photographs have been taken of this nebula by Mr. Common and Mr. Roberts. Another large *irregular* nebula is seen

FIG. 157. θ (and 42 M. Nebula) Orionis.

in the southern hemisphere surrounding the star η Argus. As an example of a *ring* nebula we add an illustration of the one in the constellation of Lyra. *Elliptical* nebulæ are probably in some cases merely ring nebulæ looked at sideways more or less. In other cases we have merely an elongated streak of light. The finest example of an elliptical nebula is the great nebula in Andromeda. Mr. Roberts, of Liverpool, obtained a most marvellous photograph of this bright nebula in December 1888. By his kind permission a reproduction of this photograph is given. Drawings of this from telescopic views had previously represented it as a rough elliptical mass broken by two unconnected dark rifts. The photograph, which shows the integrating effect of four hours' exposure, reveals

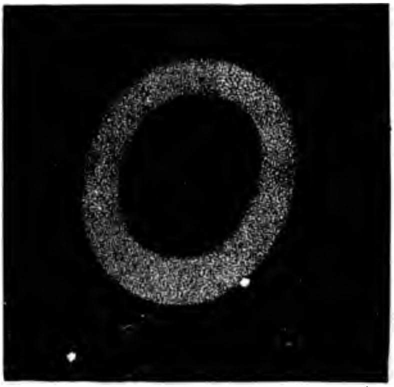


FIG 158.—Annular Nebula in Lyra.

FIG. 159.—Andromeda Nebula. After a photograph by Mr. Roberts

details never seen in the most powerful telescopes, and perhaps shows us a planetary system like our own in process of evolution. The central condensed nucleus appears to be surrounded with a spiral of nebulous matter in a plane greatly inclined to the line of sight, dark rifts separating two of the whorls of this spiral. In time the nebulous matter surrounding the central mass will probably be absorbed or separated into rings which may afterwards break up into planetary masses. The farthest boundaries of the nebula have already separated into rings more or less symmetrical with the nucleus, and present a general resemblance to the rings of Saturn, while the two smaller nebulæ seem as though they were already undergoing their transformation into planets. The photograph also shows numerous stars that were in the field of view.

Of *spiral* nebulæ the one in the constellation Canes Venatici is best known. This spiral structure can only be seen in a powerful telescope.

FIG. 160.—Spiral Nebula in Canes Venatici.

As thus seen (fig. 160), a central globular mass appears surrounded by a coil of nebulous matter, and at the outside of this coil is seen another round mass connected with the spiral by a fainter curved band. It is probable that many other nebulæ would show a spiral structure could they be seen under suitable conditions.

Planetary nebulæ usually present a nearly uniform disc of light, but in other cases there is a dark centre. Their form is circular or slightly elliptical. The one numbered 2241 in Herschel's Catalogue is shown. *Stellar* nebulæ or nebulous stars appear as stars surrounded by a hazy, nebulous ring. Two such stars appear in the constellation of Orion, and a recent photograph of the Pleiades reveals nebulosities enveloping six of the stars in this constellation. Most of the nebulæ can only be seen in the best instruments; for the more distant nebulæ are so extremely faint that a single *sperm-candle consuming* 158 grains of matter per hour at a distance

of a quarter of a mile is said to be 20,000 times more brilliant than such nebulæ. By long exposure of a sensitive photographic plate suitably fixed to an equatorially mounted telescope, pictures of nebulæ too faint for the most powerful telescopes have made their existence manifest; and the same means has shown details which were never previously seen, and which indeed never will be seen. As before intimated, changes of brightness and of form seem to go on in some of these misty objects, and both variable and temporary nebulæ have been noted.

FIG. 161.—Planetary Nebula. (H. 2241.) FIG. 162.—Stellar Nebula. (H. 450.)

230. **Spectra of Nebulæ.**—Before describing the spectra of these bodies we must remind the reader that the spectrum of a heavenly body not only indicates the chemical elements that emit the light but also its physical condition (see par. 74). Nebulæ seem to be divisible into two groups according to their spectra.

1. Nebulæ giving a spectrum of bright lines.
2. Nebulæ giving a spectrum apparently continuous.

FIG. 163.—Spectrum of Nebula. (H. 4374.)

The first kind of spectrum is given by those nebulæ which show a greenish tint in the telescope. Six bright lines have been seen in the spectrum of these nebulæ and some thirty more have been obtained in the photographic portion of the Orion nebula. A faint, narrow, continuous spectrum is also sometimes seen. Of the six or seven visible lines, three are easily visible in a good tele-spectroscope. The brightest line of the nebular spectrum in the figure λ 5004 was formerly ascribed to nitrogen, but this is now given up. Mr. Lockyer believes it to coincide with the bright edge of a low-temperature magnesium fluting; but Dr. Huggins does not find this agreement. The next brightest line, γ 4957, is also one which cannot be identified. The third line undoubtedly belongs to hydrogen,

being the $H\beta$ line of this gas, or, which is the same thing, the F line of the solar spectrum. Another line, $H\gamma$, is also a hydrogen line. The least refrangible line, λ 5874, seen in the Orion nebula is the line D_3 attributed to the matter called 'helium' in the solar prominences. The chemical constitution of the gaseous portion of the Orion nebula, so far as it is understood, seems to be the same as that of the solar prominences.

The other nebulæ, of which the Andromeda nebula is an example, are whiter and brighter than the first kind, and give only a continuous spectrum, often without any lines or bands, either bright or dark, being recognisable. From such a spectrum we can learn nothing; for we get a continuous spectrum from an incandescent gas under great pressure as well as from solids and liquids. In some cases, however, these continuous nebular spectra show maxima of brightness in certain positions. The telescope fails to resolve these white nebulæ, and the photographic plate shows them to be of the same nature as the other kind, though probably further condensed.

231. What is a Nebula?—This is a difficult question; some writers believe nebulæ to be masses of cosmical gas 'at a high temperature and very tenuous, where chemical dissociation exists.' These are the words used by Dr. Huggins in speaking of the Orion nebula. He further says: 'We know certainly that two of the lines are produced by hydrogen. The fineness of these lines points to a high temperature and condition of the great tenuity of the hydrogen from which the light was emitted. This condition of the hydrogen may give us a clue as to the probable interpretation of the other lines. These may come from substances of very low vapour-density and under molecular conditions which are consistent with a high temperature.' Professor Lockyer, on the other hand, maintains that nebulæ are clouds of sparse meteorites giving off faintly glowing vapours, the light, whether produced by electrical excitation or otherwise, giving us the lines visible at the lowest temperature of the chemical elements known to exist in meteorites. Speaking of this experiment he says: 'The result of this comparison then is that the nebula spectrum is as closely associated with that of a meteorite glowing very gently in a very luminous atmosphere given off by itself as is the spectrum of a comet near the sun by a meteorite glowing in a denser one; also given off by itself when more highly heated. Further it has been seen that the nebula spectrum was exactly reproduced in the comets of 1866 and 1867 when away from the sun. As the collision of meteorites is accepted for the explanation of the phenomena in one case it must, *faute de mieux*, be accepted for the other. The well-known constituents of meteorites, especially olivine, fully explain all the spectroscopic phenomena presented by luminous meteors, comets, and nebulæ.' These conflicting views about the constitution of nebulæ must be left till further observations and experiments become quite decisive.

232. Celestial Photography.—References have been made several times to photographs of the heavenly bodies, and a few general remarks are now added. With the ordinary telescope and spectroscope the observer avails himself of the *visual* properties of light. In photography the chemical activity of certain light-rays and of other rays beyond the violet end of the light spectrum act upon a sensitive plate and impress the image of the object sending out the rays. Beautiful photographs of the moon and of separate portions of lunar scenery were taken some thirty-five years ago. More recently fine prints of the sun's surface have been obtained by instruments called *photo-heliographs*. This is a telescope with the object-glass

corrected for the photographic rays, and having a frame to hold the sensitive plate at the eye end. In front of this frame is a spring shutter by means of which an instantaneous exposure may be obtained for the bright sun. (Par. 78.) Reflecting telescopes with a mirror of silver on glass are also used in celestial photography. The mirror is at the lower end of the tube and, arrangements are made for exposing the chemically prepared plate at the focus of the mirror. By one or other of these instruments photographs of the sun's corona during a total eclipse have been obtained, though during the short time available on such an occasion certain faint details and extensions visible to the eye do not leave an impression. Coronal photographs, therefore, show but little of the outer corona, but they are absolutely truthful as far as they go. As the range of sensitiveness of the photographic plate is being extended, we may hope for better results. The faint nebulæ and certain comets can, however, be photographed; for the long exposure needed can be given by having the photographic telescope mounted as an equatorial. It is then made to follow the object so as to keep the image on the plate by an accurate driving apparatus. In this way the magnificent portraits of the nebulæ already referred to (par. 229) have been obtained, revealing parts never seen by the human eye, even when armed with the most powerful telescope. The sensitive chemical plate of the photographer has two advantages over the human retina. First, it is sensitive to certain rays which produce no visual effect. Next it can accumulate light-impression beyond the power of human vision. What is too faint to impress the retina in a second will not reveal itself by gazing an hour; but light which is too faint to impress its image on the sensitive photographic plate in one hour may do so in two or more. Thus the feeblest luminous action will, with sufficient time, impress an image of the radiating object. Hence photography has revealed to us myriads of stars and hundreds of nebulæ never seen. The long exposure required to photograph the fainter portions of a nebula causes the brighter parts to be over-exposed, while the brighter stars in the field come out as blurred patches.

Photographic maps of the solar spectrum on an enormous scale are in progress, and these show numerous new lines in the part beyond the violet. (*See* page 84.) Thousands of photographs of stellar spectra have been obtained, and a complete spectroscopic survey of the stars down to the ninth magnitude is going on under the direction of Professor Pickering in America. Photography is also used to determine degrees of stellar brightness. It has also been found more useful than direct eye-observation in determining the displacement of the lines in stellar spectra, and it thus furnishes a satisfactory method of determining the motions of stars in the line of sight. Professor Pritchard, at Oxford, by a series of photographs, taken at different seasons, has been able to measure the parallactic orbit of certain stars and thus determine their distance. Lastly, photography has been applied to the construction of star charts. An International Congress held at Paris has arranged to divide the work of photographing the whole sky among the chief observatories of the world. The plates will be of uniform size, and each plate will cover a field 2° square. A complete celestial atlas will thus be obtained for future reference, and its permanency will be secured by an ingenious method, invented by Mr. Roberts, of obtaining a copper-plate facsimile of the photographic plates. Photography is thus effecting a revolution in the art of astronomical observations similar to that effected by the spectroscope thirty years ago. It enables us to obtain and keep accurate pictorial representations of particular objects and groups of

objects; it greatly facilitates and expedites the processes of exact measurement and of the construction of charts of the stars; it reveals to us new and wonderful phenomena; and it gives great assistance in reading the riddle of the chemical constitution and physical condition of celestial objects.[1]

CHAPTER XV.

ATMOSPHERIC AND OCEANIC MOVEMENTS.

233. **General Movements of the Atmosphere on the Earth.** —We will now return for a time to our own globe. Differences of atmospheric pressure, as measured by the barometer ('El. Phys.' chap. x.), lead to movements of the air, known as winds, the wind blowing from a region of higher towards a region of lower pressure. 'All winds may be regarded as caused directly by differences of atmospheric pressure, just as the flow of rivers is caused by difference of level, the motion of the air and the motion of the water being both referable to gravitation.' Now differences of atmospheric pressure, and consequently all winds, are caused either by changes in the temperature of the air over a certain region, or by a change in the humidity or quantity of aqueous vapour over that region, from both of which causes differences of density of the atmosphere in adjacent regions result, and atmospheric currents are then produced. Both these changes may be referred to the radiant energy of the sun. The air is heated chiefly by contact with the warm land or water-surface of a portion of the globe. As it gets warmer it expands and becomes less dense, or specifically lighter, ascending so as to produce an overflow above. The barometric pressure is thus diminished, and the heavier air of the neighbouring colder region will now flow in below, to take the place of the lighter air that has risen. Hence the statement that at the surface of the earth the wind blows from a region where the barometer is high to one where it is lower. In the case of the earth we know that the temperature of the equatorial regions is high, and that of the polar regions low. For the

[1] Excellent reproductions of photographs of celestial objects appear from time to time in *Knowledge*.

sake of simplicity we may at first suppose a uniform land or water surface. It is plain, from what has been said, that there will result an interchange of air between these two regions, an ascent of warm moist air from the regions near the equator, which will flow away in the upper atmosphere, leaving a region of low pressure; and an inflowing current of cooler air from the poles. Were the earth not rotating on its axis, these currents would flow north and south. But because of the earth's eastward rotation, these directions are materially modified. At the equator the surface velocity of a body eastward is over 1,000 miles an hour; at 45° 730 miles an hour; at 60° 500 miles an hour; at 75° 260 miles an hour, and at the poles zero. Hence the outflowing upper currents from the equator carry with them their high eastward velocity. It can be shown that this relative easterly movement is much greater than the difference between the rotatory velocities at the different latitudes, being, for a mass of air suddenly transferred from one latitude to another, as the difference of the squares of the cosines of the latitude. Cooled by the ascent, they come down to the earth's surface a little beyond the tropics, blowing towards the north-east in the northern hemisphere and towards the south-east in the southern hemisphere. But as winds are named according to the direction *from* which they blow, these winds of the temperate zones are south-west winds in the northern hemisphere and north-west in the southern hemisphere. The cold and dense winds starting from the north pole first flow near the surface, but being pushed up in the temperate zones by the south-west winds above mentioned, come down again only at the tropics, and flow along the surface of the globe in the direction of the equator. Moreover, as they bring with them from the polar regions a much smaller easterly motion than the part of the earth over which they now pass, they continually drag behind. So that their motion with reference to the earth's surface is both to the equator and to the west—i.e. we have in a belt north of the equator a system blowing from the north-east, and in a belt south of the equator another system blowing from the south-east. Close to the equator both these flow nearly from due east. Hence we see

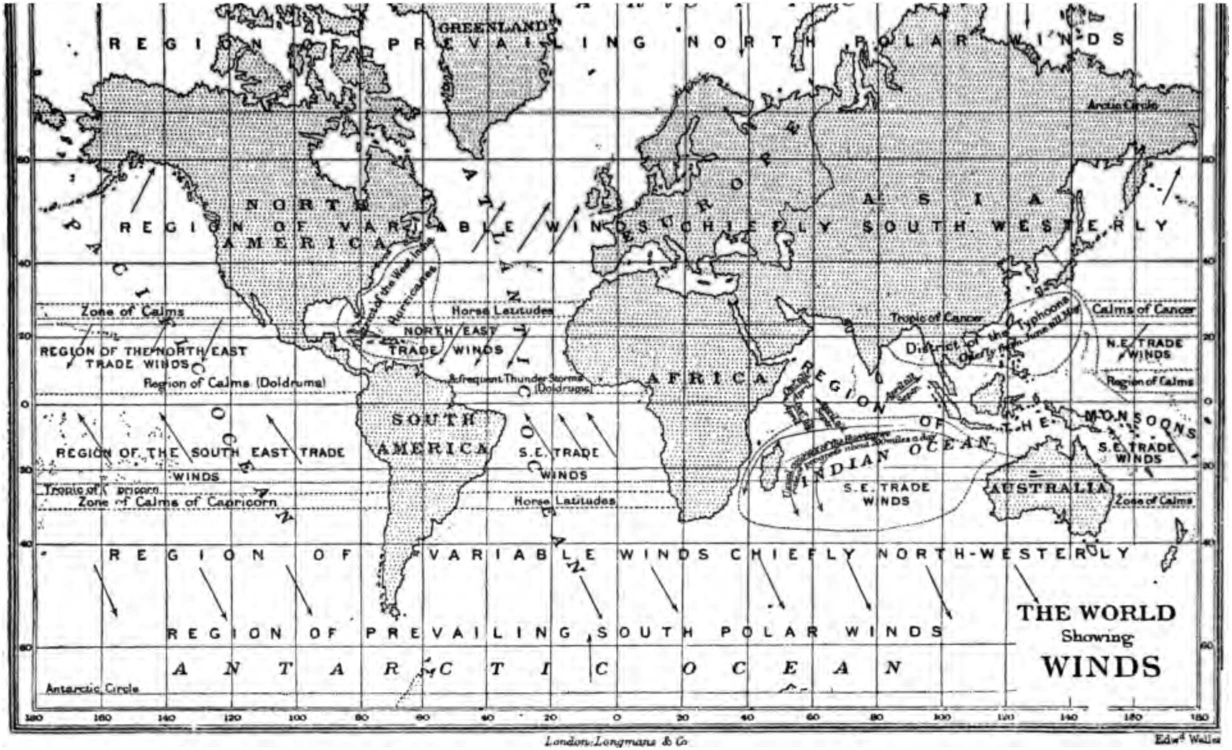
that in all cases currents of air, in moving either from the north or the south, gradually turn towards the right in the northern hemisphere, and towards the left in the southern hemisphere. Now it has also been shown that, in consequence of centrifugal force—the tendency which a body revolving in a curve round a centre has, through its inertia, to fly off at a tangent at every point of the curve—the deflection to the right in the northern hemisphere, and to the left in the southern hemisphere, is also suffered by bodies moving due east and due west. This rule applies also for all intermediate directions, and we thus arrive at the general law given by Professor Ferrel. *In whatever direction a body moves on the surface of the earth, there is a force arising from the earth's rotation which deflects it to the right in the northern hemisphere, but to the left in the southern.* This deflecting force is zero at the equator and increases with an increase of latitude.

234. **Regions of High and Low Pressure.**—Near the equator the heated air rises, and then in the upper layers of the atmosphere flows away towards the poles. This expansion of the air and flowing away will leave near the equator a region of low pressure. Into this region of low pressure, air will be driven in the lower layers of the atmosphere from regions of higher pressure, which we shall find are situated at some distance on both sides of the equator. To counterbalance this flow in the upper layers, from the equator to the poles, there must, on the whole, be a flow in the lower layers, from the poles towards the equator. This flow of air from the poles will be assisted by its centrifugal tendency—that tendency which tends to make it get farther away from the axis of rotation. So that air is flowing away from the polar regions. This cannot but produce a lowering of the atmospheric pressure on those regions, so that these polar regions are regions of low pressure. We have, then, found three regions of low pressure, namely, an equatorial region, and two polar regions. Between these occur two regions of high pressure. By observation these are found to be, in the northern hemisphere about latitude 35°, but in the southern hemisphere about latitude 30°. Let us inquire into the reasons for these regions of high pressure. Since the earth is spherical, the circles of latitude grow less as we recede from the equator; so that the air in the upper layers which is flowing away from the equator, moves in a bed constantly growing narrower. It is therefore compressed, and a part of it forced down towards the surface of the earth, its downward tendency being aided by the fact that it has become cooler and heavier since leaving the hot equatorial regions where it was first heated and expanded. This descent occurs about latitude 35° in the northern hemisphere, and 30° in the southern hemisphere, and causes the two high-pressure areas which occur in these regions. Knowing these regions of high and low pressure, we are in a position to follow the course of the chief atmospheric currents, as indicated in fig. 164.

Surface winds only are indicated within the shaded positions; but the outer part of the figure represents two layers of atmosphere, in the lower of which are surface currents, and in the higher are the upper currents. The depressions over the poles and equator indicate the low-pressure regions there. At the equator the heated air rises into the upper layers of the atmosphere, and then flows outward in these upper layers, towards the poles. Cold surface currents flow from the poles to the equator. These two large currents, to the poles in the upper layers and from the poles in the lower, are modified, as in the figure. Firstly, they are all deflected, those from the equator towards the east, and those from the poles to the west. So that the current towards the equator becomes deflected into the trade winds, north-east and south-east in the northern and southern hemispheres respectively, and extending about as far as the tropics. Between the two regions of trade

FIG. 164.

winds is the equatorial belt of calms, where the trade-wind currents join in the general upward tendency, leaving below the zone of calms and low pressure. In the northern hemisphere beyond the zone of north-east trade winds is a zone in which the prevailing winds are from the south-west. The explanation of these prevailing south-west winds is as follows. As before shown, the upper south-west current from the equator sinks down towards the earth, where it divides into two branches, part joining the north-east trade winds and flowing back towards the equator, the other


REGION OF PREVAILING NORTH POLAR WINDS
GREENLAND
Arctic Circle
NORTH AMERICA
EUROPE
ASIA
REGION OF VARIABLE WINDS CHIEFLY SOUTH WESTERLY
PACIFIC OCEAN
ATLANTIC OCEAN
Zone of Calms
REGION OF THE NORTH EAST TRADE WINDS
Region of Calms (Doldrums)
Horse Latitudes
NORTH EAST TRADE WINDS
Hurricanes
& frequent Thunder Storms (Doldrums)
AFRICA
Tropic of Cancer
District of the Typhoons
Calms of Cancer
N.E. TRADE WINDS
Region of Calms
SOUTH AMERICA
REGION OF THE SOUTH EAST TRADE WINDS
S.E. TRADE WINDS
Tropic of Capricorn
Zone of Calms of Capricorn
Horse Latitudes
REGION OF THE MONSOONS
INDIAN OCEAN
S.E. TRADE WINDS
AUSTRALIA
Zone of Calms
REGION OF VARIABLE WINDS CHIEFLY NORTH-WESTERLY
REGION OF PREVAILING SOUTH POLAR WINDS
ANTARCTIC OCEAN
Antarctic Circle
THE WORLD
Showing
WINDS
London: Longmans & Co
Edwd Weller

part keeping its direction from the S.W., usually overcoming the colder N.E. current from the poles, and giving the prevailing south-west winds of north temperate regions. So that from the two regions of high pressure winds are pressed out beneath, towards areas of lower pressure, i.e. both towards the equator and towards the poles. It will be observed that in this temperate part the cold north-east current from the poles is opposing the south-west wind (called anti-trade wind), and sometimes the one prevails and sometimes the other. So that this temperate region is a zone of variable winds, with, on the whole, a prevailing tendency from the south-west. Similar remarks apply to the southern hemisphere, where there is a north-west anti-trade wind, or rather a prevailing north-west wind. The remainder of the figure explains itself. In north polar regions the prevailing wind is from the north-east, quite overcoming any tendency of the anti-trade wind from the south-west. Similarly in southern polar regions the prevailing wind is from the south-east. But round the poles there is a considerable tract of calms and low pressure, away from which the winds gently set in all directions.

235. We therefore find, from a study of the distribution of atmospheric pressure over the globe:—

1. A belt of low pressure varying with the position of the sun, but having a mean position along the parallel of 6° N. (the Equatorial Calms).
2. An area of low pressure round each pole (the Polar Calms).
3. Two zones of maximum pressure, one about parallel 35° N. (the Calms of Cancer), the other near parallel 28° S. (the Calms of Capricorn).

As a result of the interchange of air set up between equatorial and polar regions by the unequal distribution of solar heat and of the modification produced by the rotation of the earth, we also find four systems of winds:

1. North-east Trades 9° N. to 35° N.
2. South-east Trades 1° S. to 30° S.
3. South-west Anti-trades 35° N. to 65° N.
4. North-west Anti-trades 30° S. to 65° S.

236. **Trade Winds.**—The trade winds are constant winds on each side of the equatorial zone of calms. This equatorial calm belt, known as the 'Doldrums,' is a region of low pressure nearly parallel to the equator and from 3° to 8° in breadth. It is characterised by great thunderstorms and much rainfall, alternating with long periods of calm and suffocating heat. In the Atlantic Ocean it lies wholly to the north of the equator; but its position varies with that of the sun, reaching its most northerly limit, lat. 11° N., near the end of the northern summer, and its southern limit 1° N., towards the end of the northern winter. In the Pacific Ocean the calm belt passes a little to the south of the equator in the southern summer. The belt in which the trade winds blow occupies a zone of about 20° on each side of the calm-belt near the equator. These winds advance from the north towards the region of low pressure about the equator; but, in consequence of the earth's rotation, they are deflected towards the west, and as a consequence we have north-east trade winds in the northern hemisphere and south-east trade winds in the southern hemisphere. In the Indian Ocean the trade winds are only constant in the southern hemisphere; in the north they are interrupted by the great mass of land forming the continent of Asia.

237. **The Anti-trade Winds.**—The low barometric pressure near the

equator is caused by the heated air of this region rising up and overflowing towards the poles. These upper currents move at first at a great height above the trade winds, but gradually descending reach the level of the sea about the thirtieth parallel of latitude. Here they give rise in each hemisphere to the districts known as the calms of Cancer and Capricorn, and cause a high barometric pressure to prevail, except in parts where there is irregular local heating of the land surface in the neighbourhood. The district of high pressure in the North Atlantic about lat. 30° to 35°, between the United States and Africa, is known to seamen as the 'horse latitudes,' and is characterised by calms and variable winds. It is the region where the mass of floating weed known as the Sargasso Sea is found. Beyond the tropical belts of high pressure the anti-trades that have come to the surface must continue their journey towards the poles, and, as already explained, must become deflected by the earth's rotation to the right in the northern hemisphere, and to the left in the southern hemisphere. Hence, in the temperate zones we have the prevailing winds westerly. In the northern hemisphere these south-west winds are fairly constant over the oceans, but the influence of the great continental land masses on which changes of temperature occur to a great extent, and more quickly than on the ocean, disturb the regularity of these currents. In the southern hemisphere, however, where there is little land to cause a disturbance, these south-west winds blow, especially in the Pacific and Indian Oceans, between latitudes 40° and 50° so strongly and steadily as to take the name of 'The Roaring Forties.'

238. **Monsoons.**—The general circulation of the atmosphere which arises from the difference of temperature between the equatorial and polar regions, is only subject to annual variations due to the changing position of the sun in each hemisphere. There are other atmospheric disturbances less general, arising from difference of temperature in the atmosphere overlying great land masses, and that overlying the surrounding ocean. The chief of these are the Monsoons (seasons), so called because of their dependence on seasonal change of temperature. Of these, the monsoons that prevail in India and over the Indian Ocean, are best known. As the sun passes towards the tropic of Cancer in the northern summer, the southern slopes of the Himâlaya Mountains, the desert of Gobi, and the great plains of Central Asia become greatly heated, and the air resting on these regions becomes warm and ascends. From all sides air flows in towards the heated interior, and being deflected to the right by the earth's rotation, the winds coming from the Indian Ocean come from the south-west and produce the south-west monsoon, which blows from May to October over the northern Indian Ocean towards the district of low pressure in Central Asia. Thus during these months the north-east trade winds of this district are completely broken up and reversed. These south-west monsoons coming from equatorial regions are almost saturated with moisture, and as these vapour-laden winds strike against a range of mountains, the air is forced to ascend, dynamical cooling follows, and the moisture is precipitated as rain. The latent heat given out during the condensation of the aqueous vapours adds greatly to the strength of the south-west monsoon. The current of the south-west monsoon from the Arabian Sea first meets the Western Ghauts on the Malabar coast of India. Here a large part of its vapour is condensed and there is an immense rainfall. Passing onwards it next begins to ascend the southern slopes of the Himâlayas, where its remaining moisture is precipitated in copious showers. But the greatest

rainfall occurs on the Khasia Hills in the district at the north of the Bay of Bengal. The monsoon of the Bay of Bengal has a more northerly direction than that of the Arabian Sea, and its warm, moist air from equatorial regions is somewhat concentrated on these hills; and these, being the first elevations it has met, receive to the full the precipitated moisture as the wind ascends the slope. During the period of the south-west monsoon, 30 inches of rain often fall for several successive days, and the total rainfall for a year averages about 600 inches or 50 feet. The vast amount of rainfall during the summer monsoon has led to its being called *the wet monsoon.* As the summer monsoon begins to break up in October, variable winds, calms, and hurricanes occur in the Indian Ocean. About the beginning of November, the land surface of the interior of Asia and the slopes of the Himâlayas have cooled down again, and, as winter draws on, the cold, dry atmosphere of the plains of the interior leads to an increase in the density of the air, and we have now a high barometric pressure at the centre of this continent. As a consequence there is a complete reversal of the air-currents between the central and the surrounding regions. The cold dry air flows down the slopes of the Himâlayas towards the sea and we have the north-east monsoons of winter. These monsoon winds combine with and strengthen the regular north-east trades, but still are not so strong as the south-west monsoons. As the north-east monsoons come from the elevated and dry plains of the interior into warmer and lower regions no moisture is precipitated from them, and they are often called *the dry monsoons.* Monsoon regions also occur in tropical America and in Australia. These depend on the same causes, the annual alternations of temperature in the interior of these continents. In the summer the heated interior leads to a rarefaction of the air overlying the land, and there is a general tendency for the wind to blow from the sea to the land. In winter the tendency is for the wind to blow from the land to the sea. But the monsoon-influences about the other continents are comparatively small compared with those of Asia. This is owing to their smaller extent, and especially the absence of high mountain ranges and plateaux. For 'if the surface of the continent is convex, or if it has highlands with long slopes, or the interior is in almost any way considerably elevated above sea-level, the tendency in the case of the summer monsoon to flow in from the ocean toward the interior of the continent, or the reverse in that of the winter monsoon, is very much increased.'

239. **Occasional Winds and Storms.**—Another class of atmospheric disturbances is of a more local and temporary character. Occasional winds, called *storms,* when the movement of the air is violent, arise from local increases of temperature above the surrounding parts. Land and water, dry and marshy areas, have different heat radiating and absorbing powers, and it thus happens, in a certain circumscribed area, that the temperature of the air becomes higher than that of the surrounding atmosphere. The air from this heated area begins to rise up and spread out in all directions above, giving rise to a region of low pressure on the earth's surface beneath this ascending current. During its ascent the air becomes cooler through expansion, but this decrease of temperature leads to the condensation of its water vapour, and there is thus liberated all the latent heat taken up during the process of evaporation. This further rarefies the ascending current and strengthens the vertical circulation, moist air being drawn in from all sides to supply the upward movement in the area of low pressure. Ascending currents, produced as above described, give rise to clouds, and rain frequently

follows. Such regions of low pressure, with their accompanying winds, are called *cyclones*, and all storms have a cyclonic character. Several cyclones are often found to exist simultaneously in the temperate zones. One may extend so as to include another, or a large cyclone may separate into two. Ordinary cyclones are never stationary, for their centres move onward generally in the direction of the prevailing winds. Hence tropical cyclones move westwards and towards the pole, while the cyclones in temperate zones move in an easterly direction towards the pole, and with a greater velocity. Thus a cyclonic path if completed would be somewhat in the form of a parabolic curve, with its vertex near the tropical calm-belt.

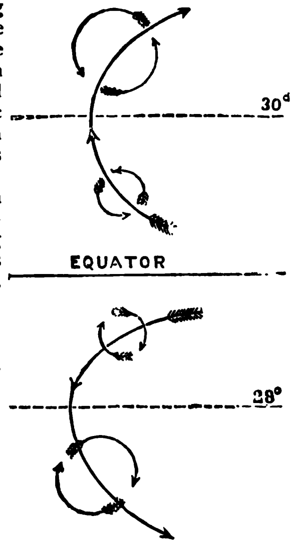


FIG. 165.—Paths of Cyclonic Areas.

Between adjacent cyclones will often be found a district of relatively high pressure, from which gentle winds are passing spirally in all directions. These winds flow in a contrary direction to those in a cyclone. Thus two distinct areas of barometric pressure are found to prevail, and these are connected with two distinct sets of atmospheric movements. The winds either blow inwards in a gyratory or whirling manner from all sides *to* a centre of low pressure, or outwards on all sides *from* a region of high pressure. Places where the barometric pressure is equal are connected by a line passing through them, called an *isobar*. The winds are strongest where the isobars are nearest together, or in other words, they are generally proportioned to the barometric gradient.

240. **Barometric Gradient.**—Engineers measure the inclination of a road or railway by what they called the *gradient*. A gradient of one in fifty indicates that the slope rises one foot for every 50 feet of horizontal length. Meteorologists also use gradients, and those adopted are expressed in hundredths of an inch of the mercury in the barometer per fifteen nautical miles. Thus a gradient of 3 implies a difference of ·03 inch in a distance of 15 nautical miles. If the barometer at Brest read 27·38 at 8 A.M., and at Penzance at the same hour 29·19, we get a difference of reading of 0·19 inch. The distance from Brest to Penzance is 113 miles. By simple proportion we find that a difference of 0·19 inch in 113 miles gives a difference of 0·025 in 15 miles. The resulting gradient is therefore 2·5.

The greater the difference of barometric reading between two places, the steeper, so to speak, will be the barometric gradient, and the stronger will be the winds; for it is found that winds, as regards their direction and force, bear a definite relation to these gradients in accordance with the law of Buys-Ballot. This law *may* be stated thus: *Stand with your back to*

the wind, and the barometer will be lower on your left hand than on your right. As thus expressed the law holds good for the northern hemisphere except close to the equator; in the southern hemisphere we must interchange left and right.

241. **Anemometers.**—The force of the wind can be measured by an anemometer, which will show the pressure on a given area. Robinson's hemispherical cup anemometer determines the velocity of the wind. These hemispherical cups are attached to the ends of two horizontal rods forming a square cross. The cross rods are attached in a horizontal position to a vertical axis, about which they turn freely. The cups, so arranged as to catch the wind in whatever direction it may be blowing, cause the rotation of the vertical rod, and this is communicated to a series of index-wheels, from which the velocity of the wind may be read. In the Daily Weather Report, the wind is not measured by any instrument, but is estimated according to a scale prepared by Admiral Beaufort.

242. **Cyclones.**—We have seen that cyclones are areas of low barometric pressure with an encircling system of winds blowing spirally inwards. Such an area is determined when a sufficient number of observations are made on a given day at a fixed hour and communicated by telegraph to a central office. These observations will show that the lowest reading of the barometer covers a certain area, and this area is usually found to be more or less circular. Suppose this area of low pressure has a barometric reading of 29·55 inches. The space included in it is then connected by a line showing this reading. A short distance all around this spot, places will be found where the barometer stands at 29·6, and these places are now connected by another isobar or line of equal pressure. At a further distance, but still in a more or less circular form, observers will report a barometric reading of 29·7 inches, and thus another circular isobar is found. This process may go on till the highest readings are reached, though it will be found that the outer lines become less regular (fig. 166). Moreover, the distance between one reading and another will not be uniform all the way round, so that the isobars will be closer together at certain parts than at others. Thus a cyclonic area is a region of low pressure, from the centre of which the barometrical readings increase in all directions.

It is not necessary that the barometer should be of any particular height in such an area, but only that it should be low *in relation* to the surrounding readings. A cyclonic depression may vary from 30 to 1,000 miles in diameter. In the northern hemisphere it is found that there is a spiral inflow of the winds towards a cyclonic area, in a direction contrary to the hands of a watch. Cyclonic systems may also be described as bad weather systems; for they bring to the region which they cover a large amount of cloud and rain, producing comparatively warm wet weather in winter and cool damp weather in summer.

243. **Anti-cyclones** are areas of high pressure from the centre of which the barometrical readings decrease in all directions, and from which gentle breezes blow spirally outwards. This central area is usually larger than a cyclonic area, and the surrounding isobars lie further apart than in cyclones, the winds consequently having less force. The direction of the winds is the same as the hands of a watch. An anti-cyclonic system is marked, at least at its centre, by dry and fair weather, though fog is often present. Thus it produces the hottest weather in winter and the coldest in summer. These circumstances are accounted for by the fact that the air flowing out from the centre must be replaced from the upper regions. Air descending undergoes compression, and its temperature rises in the process, so that its capacity for moisture is increased and it feels dry. Both cyclones and anti-cyclones have one attribute in common. In both cases there is a calm at the centre enclosed by the innermost isobar, while around this calm

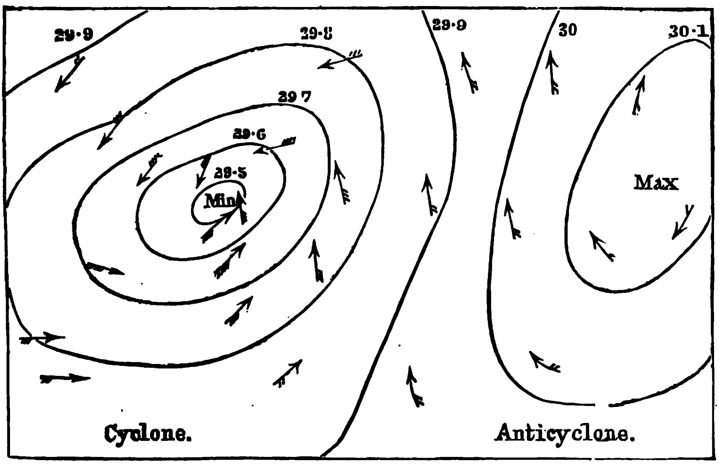


FIG 166.—The stronger winds are indicated by the amount of feathering on the arrows.

centre the winds circulate in both cases. But in other respects there is a great contrast. The winds blow in exactly opposite directions in the two cases, and usually with a different force. With the cyclones come rain or snow, squalls and cloudy skies; with the anti-cyclones comes generally bright, and always dry, weather. The former move on more quickly and with more uncertainty; the latter pass off slowly, or may remain stationary for some time.

244. **Examples of Cyclones and Anti-cyclones over the British Isles.**—From 'Weather Charts and Storm Warnings,' by R. H. Scott, we extract the following. The reader will find in this work an admirable account, with many illustrations, of the weather of our islands. Fig. 167 'gives a good example of an area of low pressure, or a "depression," or a cyclonic disturbance, for the terms are used almost indiscriminately, developed as fully as it is usual to find them in Western Europe.

' It will be noticed that the chart contains other indications, besic afforded by the isobars, which require some explanation. The (and force of the wind are given by arrows: a circle indicates a the wind has neither direction nor force. The direction is show

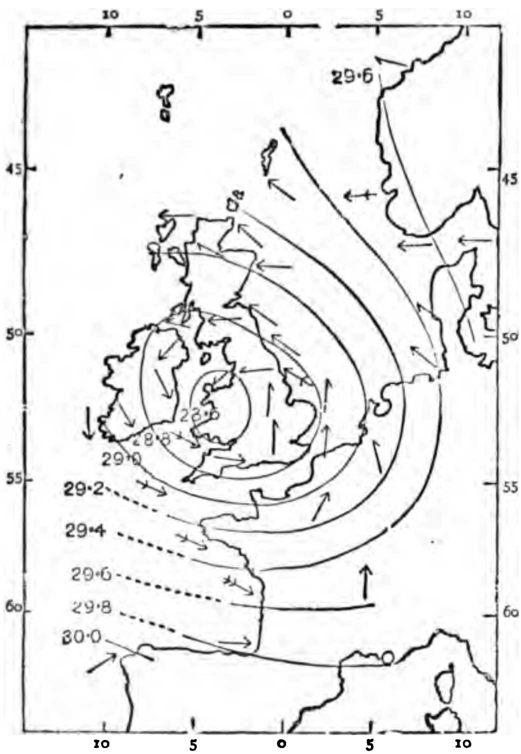


FIG. 167. – November 29, 1874, 8 A.M. Isobars and Wind, Cyclonic Sys

direction in which the arrow is flying. The force is indicated by di in the symbols employed, which are as follows:—

				Miles per l
Forces	0–1	(Beaufort scale)	⊙	3 to
,,	2–4	,,	⇀	13 to 2
,,	5–7	,,	→	28 to 4
,,	8–10	,,	⋙→	48 to 6
,,	above 10	,,	⋙→	75 to 9

Thus it will be seen that there is a very heavy gale at Rochef

W., a heavy gale at Scarborough from SE., a fresh breeze at Aberdeen E., a light breeze at Brussels from SSE., and a calm at Toulon.

The lowest reading (28·55 inches) is at Holyhead; the highest (30·00 es) at Corunna.

The innermost isobar (28·6) embraces almost the whole of Wales. t for 28·8 is oval in shape, and covers nearly all England, and the and north of Ireland. That for 29·0 takes in a little of France and

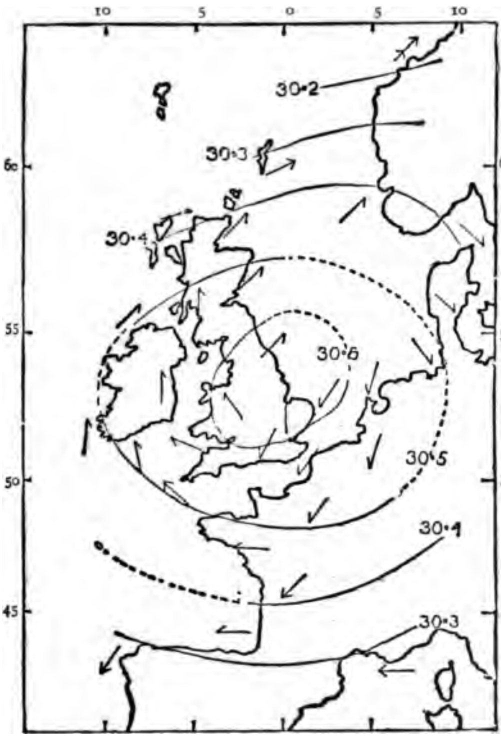


FIG. 168.—February 4, 1874, 8 A.M. Isobars and Wind, Anticyclonic System

gium, and the greater part of Scotland. The isobar of 29·2 envelops whole of Scotland, but is not carried out over the Atlantic beyond the neys on one side and the coast of Brittany on the other, and it is only ed in, as being merely inferred, in the absence of observations, over Bay of Biscay.'

The chief feature noticeable in the northern part of the chart is that the urs of *29·4 and 29·6* trend away to the northward, and so the curves *d out in a fan shape* between the Shetlands and the coast of Norway.

'If we now turn to the wind-arrows, we shall find that they show a circulation round the centre of depression. They are :—

Westerly at Scilly and in France . . .	on its southern side.
Northerly at Valencia; North-north-east at Donaghadee . . .	on its western side.
East at Ardrossan	on its northern side.
South-east along the whole east coast of Great Britain north of Hull; South at Yarmouth and in the Straits of Dover	on its eastern side.

'In fact the wind sweeps round the central area of depression, *against watch-hands*, and this is the invariable law in all cases of cyclonic disturbances in the northern hemisphere. . . .

'Let us now take the converse case, an instance of an area of high pressure, or an anti-cyclone, and for this we have an excellent example in February 4, 1874 (fig. 168). On this day, at 8 A.M., the absolute highest reading is 30·67 at Nottingham, and the only English reports which give readings below 30·6 are Dover, Plymouth, and Scilly, the isobar of 30·6 enveloping almost the whole of England and Wales. That of 30·5 stretches to Holstein near Fanö (30·49), passes south of Paris (30·52), being shown by dots, owing to deficient information, between these points, sweeps close to Valencia (30·49), is again dotted over the sea outside the coast of Ireland, and finally reaches Aberdeen (30·49).

'In the north and south readings decrease rapidly; on the south side, the curve for 30·40 passes half-way between Rochefort and Biarritz, and 30·30 skirts the coast of Spain and the Pyrenees, readings being 30·28 at Corunna, and 30·24 at Toulon. In the north 30·4 passes below Stornoway (30·39), runs between Wick and Thurso and across to Jutland, where the reading at the Scaw is 30·34. Passing farther north, 30·30 runs close to Sumburgh Head and across to the neighbourhood of Bergen in Norway, while above it still we find that of 30·20, the reading at Christiansund being 30·15.

'When we look at the winds in this case we find that their circulation is exactly opposite to that which is shown in fig. 167; it is *with watch-hands*, being:—

North	in Germany, on its eastern side.
East	in France, on its southern side.
South	in Ireland, on its western side.
South-west to west .	in Scotland, on its northern side.
North-west . . .	in Denmark, on its north-eastern side.

'The arrows also appear to draw *out from the centre* instead of *drawing in towards it*, as in cyclonic systems.

'The isobars are further apart than in the former case, and in consequence the force of the winds is much less.'[1]

245. **Tornadoes, Hurricanes, Typhoons, &c.**—The general name cyclone belongs to all storms in which the air-currents follow a more or less spiral or whirling course. *Tornadoes* are local cyclones of great violence and of comparatively small extent. They last but a short time, and most frequently occur during the sultry afternoons of summer. A warm moist column of air resting on the rarified layer next to the ground suffers a

[1] A knowledge of the paths of cyclonic areas (par. 239) and of the existence of such an area with the barometric pressures in it and surrounding it, often leads to successful *weather-forecasting*.

slight disturbance, and an uprush of the air of the lower strata through those above sets in, and this is followed by [illegible] that meet from all sides below. These whirling winds attain [illegible]. the pressure at the centre is greatly diminished, and [illegible] cooling as it expands, forms a funnel-shaped cloud [illegible] hanging downwards. As a consequence of the [illegible] pressure at the centre, strange and violent [illegible]. Vessels burst, doors and walls of houses are thrown [illegible], and even the roof is hurled up and blown away, by the [illegible] of the interior air, thus suddenly relieved of a [illegible]. The whirling blast of air at the surface scatters the lighter [illegible], and even blows down the houses, trees, [illegible] while fowls, men, and various kinds of heavy bodies, may be drawn [illegible] and thrown out above in all directions. As the [illegible] narrow track, seldom exceeding a quarter of a mile in width, it leaves behind a path of destruction and desolation. [illegible] itself after passing twenty or thirty miles. The rapid [illegible] of air in a tornado leads to a great amount of rainfall. [illegible] fall may be prevented by the violence of the up-draught [illegible] the water at times comes down in continuous [illegible] as *cloud-bursts*. Thunder and hail also frequently accompany [illegible].[1] When a tornado occurs at sea, the funnel-shaped cloud may [illegible] the surface and draw up into it the whirling spray. [illegible] column of water and air is called a *water-spout*. It must [illegible] that the real spout is formed by the depending cloud, the water [illegible] the sea or lake being a secondary matter. A water-spout [illegible] the cloud brought down to the earth's surface by the [illegible] of the aqueous vapour in the rapidly gyrating [illegible]. In [illegible] of dust are often lifted up into the vortex of a [illegible] *sand-spouts*. Small dust-whirlwinds may sometimes be seen on hot turnpike roads. Tornadoes are frequent in the United States, especially around Kansas, but similar storms are found to prevail in most parts of the world. In the West Indies they are called *hurricanes*, and in the China Seas, *typhoons*. The *simoom* is a hot, suffocating whirlwind which passes over the deserts of Africa and Arabia, and which often carries with it columns of burning sand.

246. **Currents.**—The waters of the sea are continually passing from one region to another in stream-like masses known as currents. The causes of these marine currents are, to some extent, still in dispute. Some writers make the unequal temperature of the polar and equatorial regions the primary cause ; for the colder and denser waters tend to sink, while the warmer and lighter waters, being expanded, flow over the surface. Hence arise under-currents of cold water, flowing from the poles towards the equator, and warmer surface-currents. The unequal evaporation in polar and equatorial regions is also brought forward as an efficient agent in producing these move-

[1] See note, page 331.

ments. One result of this is to produce different degrees of saltness in the waters of the sea. Thus in the tropics the surface water will be heavy through excess of salt, as the evaporation is so great; while the great rainfall in the district of equatorial calms and in certain parts of the temperate zones of the sea will result in lighter and fresher water being found there. Such unequal densities in different parts of the ocean must set up movements, for the salter water will subside and flow off as an under-current, and an inflow of fresher and lighter water will come in to make up the deficiency. The axial rotation of the earth also plays an important part, deflecting all the ocean streams to the right in the northern hemisphere and to the left in the southern hemisphere, in accordance with the principle enunciated by Ferrel. (It must be noted that currents are named according to the direction *towards* which they flow—winds according to the direction *from* which they blow.)

But, according to many of the best authorities, the primary cause is to be found in the prevailing winds of the globe, the other influences mentioned—unequal temperature-distribution, rotation of the earth, evaporation, and degree of salinity—no doubt, acting as secondary causes. An objection to the wind theory may present itself to the reader. It is known that even in great storms the water of the sea is only affected to a little depth. How, then, can a current 300 to 400 fathoms deep be produced by winds? The reply is that winds blowing *constantly* in one direction so act on the water as to produce a surface movement which in course of time is transmitted by friction from layer to layer; so that at length, the onward movement of the upper particles is communicated to a considerable depth. The movements thus established must of necessity draw the remaining waters into the general circulation.

247. **Equatorial Currents.**—By the influence of the trade winds and the earth's rotation there are, in all the great oceans, currents near the equator flowing westwards, and, but for the interruption of the land, there would be a continuous westerly stream round the globe filling the greater part of the width of the tropics. But this equatorial stream is interrupted by the east coasts of America, the East Indian Archipelago, and the

east coast of Africa, and the westward equatorial flow is thus separated into three systems. Each of these equatorial currents is thus deflected towards the north or south pole by land masses, and Professor Haughton calculates that the total volume of the equatorial currents is six and a half times that of the Gulf Sream, and that they carry away, to distribute in the temperate zones, more than half the heat derived by the torrid zone from the solar rays. A contrary effect is produced by the polar currents, which convey, chiefly from the open Antarctic Ocean, their cold waters to temper the burning heat of equatorial seas and shores.

248. **Oceanic Circulation of the Atlantic Ocean.**—The main equatorial current of the Atlantic flows across the ocean from the African towards the South American coasts. Some distance from Cape St. Roque it bifurcates, one branch passing southwards as far as the mouth of the La Plata, forming the Brazilian current, and the other branch flowing along the coast of Guiana towards the Caribbean Sea. This part unites east of the Lesser Antilles with a portion of the north equatorial flow that has crossed the Atlantic from the Cape Verde Islands. If the reader will refer to a map of the West Indies it will assist him in what follows. 'Between the Lesser Antilles and the South American coast, an offshoot of the equatorial current enters the Caribbean Sea, in the deep basin of which it is partially checked by a shoal extending from Honduras nearly to Jamaica. The current is thus turned round so as to pass eastward along the south coast of San Domingo, and rejoin the main current near Porto Rico. This washes the north shores of Porto Rico and San Domingo, and is divided by Cuba into two streams, one of which flows on its north side to the Bahama Banks. The other passes through Bartlett Deep between Cuba and Yucatan, then turns northward through Yucatan passage, then eastward through the Florida Strait, where it unites again with the other stream. Here, at its narrowest part, its width is but little over 40 miles, the depth does not exceed 3,000 feet, and the velocity at the middle is nearly five miles an hour.' This paragraph on the origin of the Gulf Stream was written by Professor Stevens in Appleton's 'Physical

Geography,' and gives the result of the investigation of Captain Bartlett, of the U.S. steamship 'Blake.' From it we learn that, contrary to the popular notion, only a moderate part of the

great body of warm water called the Gulf Stream actually passes through the Gulf of Mexico, for the greater part of the current is formed by the water from the equatorial current that enters the Gulf Stream north of Florida Strait.

(See Map, where, however, a current entering the Gulf Stream north of the Bahama Islands should be shown.)

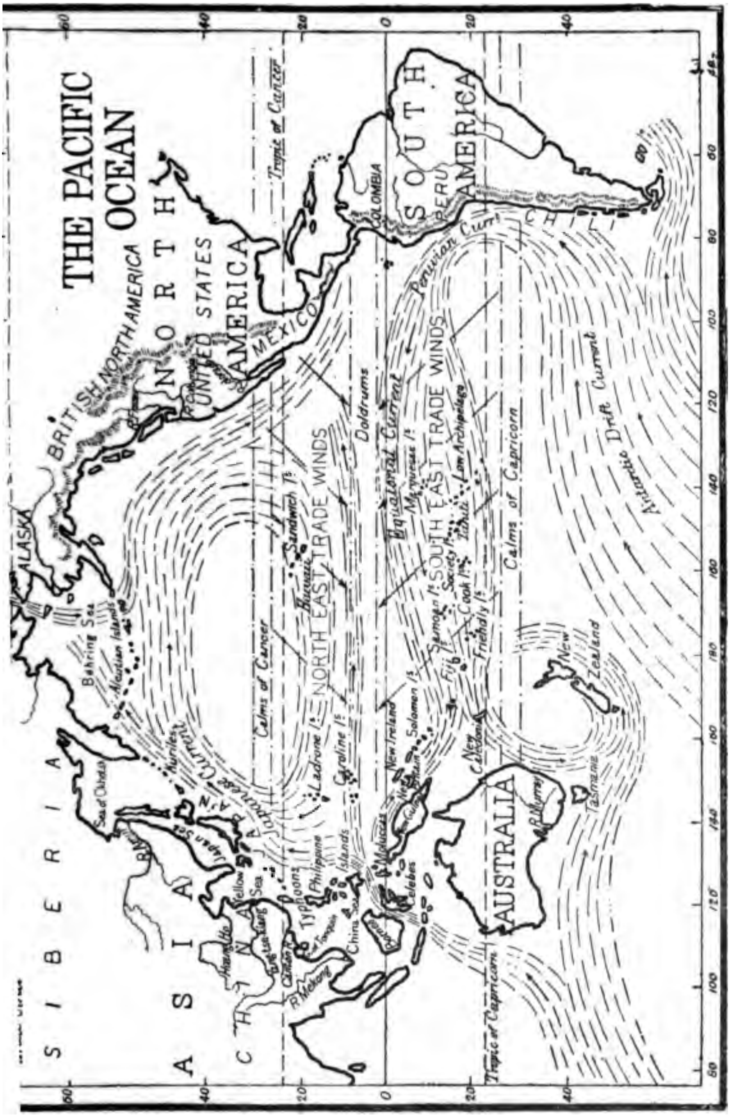
After passing the peninsula of Florida, the Gulf Stream flows north-east, increasing in width, but diminishing in temperature, depth, and velocity. Just beyond the Florida Strait it is 40 miles wide and 440 fathoms deep, and has a velocity of over four miles an hour, and a temperature of 85° F.; near Newfoundland it is 320 miles wide, has a depth of less than half the above, a velocity of only about a third, and a temperature of 60° F. (See also 'El. Phys.' par. 184.) Near the middle of the Atlantic, lat. 47° N., long. 25° W., where the stream is 800 miles wide, with a temperature still 8° or 10° above the surrounding water, a division takes place. One branch flows on and is drifted towards the north-east by the winds till it impinges on the shores of the British Isles and Norway. The other division of the Gulf Stream passes along the coast of Spain and Africa, and at last rejoins the north equatorial current, thus completing a great oval whirl through the North Atlantic. In the midst of this oval whirl is the calmer water covered with a species of sea-weed, and known as the Sargasso Sea. The influence of this great deep blue ocean river on the climate of Britain and North-west Europe is remarkable. Professor Haughton calculates that the volume of warm water poured into the North Atlantic by the Gulf Stream amounts to nearly 38 cubic miles per hour, and this transfer of heat from the tropics to the north temperate zone is more than $\frac{1}{12}$ of the total heat received in the year from the sun by the torrid zone. Hence it is found that the greater part of the British Isles has a mean winter temperature more than 20° higher than that naturally due to its place on the globe. On the map the lighter arrows indicate the cold currents from the Arctic Ocean. A strong southerly flow down the east coast of Greenland joins another cold current from Davis's Strait and forms the Arctic current, which extends southwards along the American shores till it meets the Gulf Stream. Under its chilling influence Labrador and Newfoundland are but frozen wastes during a great part of the year; and as it brings a large number of icebergs, most of these are melted and deposit their rocky burdens to form the

shoals called the Newfoundland Banks. The fogs of this island are also due to the conflict of the cold waters of this current and the warm waters of the Gulf Stream. South of Newfoundland the line of contact between these two streams is so abrupt and well-defined that it is spoken of as the 'Cold Wall.' The cold current from the Antarctic Ocean is deflected eastward, in the South Atlantic, to the shores of South Africa.

249. **Oceanic Circulation of the Pacific.**—A cold current from the Antarctic passes in a general north-east direction to the shores of South America, where it is known as the Chili or Peruvian current. Gradually becoming warmer it turns westward at about 20° S. lat., and merges into the great equatorial current of the Pacific. This last-named current, formed of a northern and southern part, occupies the entire width of the torrid zone, and is driven westwards by the trade winds to the East Indies. Here it is broken up into several portions, a part passing into the Indian Ocean. One large part, however, sets southward and carries its warm waters past Australia and New Zealand. This is spoken of as the New South Wales current, and is ultimately lost in the Antarctic Ocean. Another portion turns northward past the Philippine Islands. Now setting north-east it forms the well-known Japan current, Kuro-Siwa. Kuro-Siwa means 'black stream,' and is so called on account of the deep-blue tint of its waters.

The Kuro-Siwa, or Japanese Current, resembles the Gulf Stream in its course and character, but it appears to be formed on a much larger scale. At its narrowest part, near the Island of Formosa, it has a velocity of more than three miles an hour, and it probably transfers three times as much warm water as the Gulf Stream from the tropics to the north temperate zone. East of Japan it divides into several branches, the largest of which sweeps round and reaches Alaska and British Columbia, whose winter temperature is raised just as the Gulf Stream raises that of Britain and Norway.

250. **Currents of the Indian Ocean.**—North of the equator *the currents* of the Indian Ocean are regulated by the monsoons.


THE PACIFIC OCEAN
NORTH AMERICA
SOUTH AMERICA
ASIA
SIBERIA
CHINA
JAPAN
AUSTRALIA
ALASKA
BRITISH NORTH AMERICA
UNITED STATES
MEXICO
COLOMBIA
PERU
CHILI
NORTH EAST TRADE WINDS
SOUTH EAST TRADE WINDS
Doldrums
Equatorial Current
Calms of Cancer
Calms of Capricorn
Tropic of Cancer
Tropic of Capricorn
Peruvian Curr.
Antarctic Drift Current
Japanese Current
Behring Sea
Aleutian Islands
Kuriles
Japan Sea
Yellow Sea
China Sea
Philippine Islands
Typhoons
Ladrone Is.
Caroline Is.
Sandwich Is.
Marquesas Is.
Low Archipelago
Tahiti
Society Is.
Cook Is.
Samoan Is.
Fiji Is.
Friendly Is.
New Zealand
Tasmania
New Caledonia
Solomon Is.
New Ireland
Moluccas
Celebes
R. Murray
R. Mekong

In the southern part there is a steady westward drift, splitting, however, into two parts near Madagascar. One branch runs along the eastern shores of that island and joins the Antarctic drift current. The other branch flows to the south in the Mozambique Channel, and, passing the extremity of Africa, as the Agulhas current, carries its warm waters as far southwards as the islands of St. Paul and Amsterdam.

CHAPTER XVI.

TERRESTRIAL MAGNETISM.

251. **The Earth a Great Magnet.**—A freely suspended magnetic needle or compass needle has the property of setting itself nearly north and south.

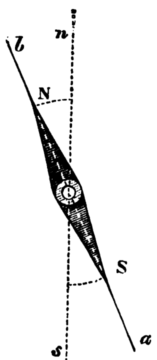


FIG. 169.—Declination of Compass Needle.

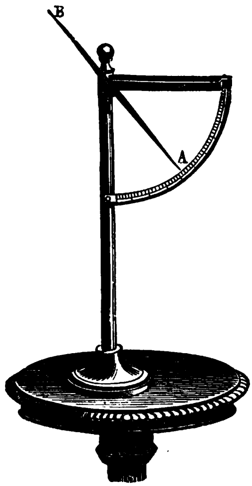


FIG. 170.—Inclination Compass, or Dipping Needle.

This is due to the fact that the earth itself is a great magnet. Its poles and neutral line, however, do not coincide exactly with the geographical poles and equator. Like other magnets, the earth attracts the opposite

poles of a magnetic needle, and causes the poles of this needle to lie in the direction of the line joining the magnetic poles of the earth. The north magnetic pole of the earth was discovered by Sir James Ross, and is situated in lat. 70° N. and in long. 96° 43′ W. The position of the south magnetic pole has not been found, though from certain calculations it is believed to be in lat. 75° 30′ S. and in 154° E. long.

This simple theory of two magnetic poles will be somewhat modified further on. For the sake of clearness we repeat certain definitions given in the 'Elementary Physiography.'

Declination.—The geographical meridian of a place is the imaginary vertical plane passing through this place and the two geographical poles. It is usually indicated by a line on the surface of the globe. The magnetic meridian is the vertical plane passing through the two poles of a freely suspended magnetic needle, and which, being produced in both directions, also passes through the magnetic poles of the earth. These two meridians do not coincide, and the angle which the direction of the needle makes with the geographical meridian is called the *declination* or *variation* of the magnetic needle. The declination is said to be east or west according as the north pole of the needle is to the east or west of the geographical meridian. Thus, in fig. 169, *a b* is the direction of the magnetic meridian, and *s n* the direction of the geographical meridian. The angle formed between the two meridians at any place is the declination of the needle at that place. The declination varies at different places. At present it is to the west in Europe.

252. **Inclination or Dip.**—When a needle is supported on a vertical pivot so as to remain quite horizontal, it is found that on being magnetised it no longer remains horizontal, but at London the north end of the needle dips down and forms an angle of about 67° 30′ with the horizontal plane. In order to see the dip accurately the needle must be placed in the magnetic meridian. The angle which a magnetic needle capable of vertical movement makes with the horizontal plane is called the inclination or dip, and a needle so poised is called a dipping-needle. The dip varies in different parts of the world. On going north of London the dip increases; on going south the dip diminishes. The *magnetic equator* of the earth, or neutral line, is the line connecting those places where there is no dip, and the magnetic poles of the earth are the places where the dipping-needle is vertical.

It would seem as if the magnetic poles of the earth were some little distance below its surface; and the dip of the needle is caused by its north-seeking end always pointing down towards the earth's north-magnetic pole, which is below its surface. (North-seeking pole is a convenient and unmistakable name for that end of the needle which points north, and which really has south magnetism, because it must be of the opposite kind to the earth's north magnetism which attracts it.) An idea of the earth's magnetic action may be very fairly got by assuming that it is caused by a great magnet buried under its surface the axis of which is inclined at about 20° to the earth's axis of rotation. Representing this by a wooden ball in which is buried a magnet, N S, see fig. 171, it will be readily understood that a magnetic needle *n s* suspended over different parts of the ball will dip down towards one of the poles of the larger magnet. Thus at the magnetic equator the needle will be horizontal, being equally attracted by the two poles N and S. But at any other position, as in the second figure, the attraction of the pole S will be the stronger and cause the needle to

dip down towards it. When the needle is vertically over the pole it will dip down in a vertical line corresponding to the positions called magnetic poles of the earth. (See also next par.) It is to be observed that the earth's magnetism is merely directive and not translative; thus it merely makes a floating needle point north and south, and does not make it move off bodily in any direction. This is natural, for the very distant pole of the earth attracts one end of the needle, but repels the other end with an equal force, so that the final result is to twist the needle round into a north and south direction, but not pull one way more than the other. (In Mechanics this action of the earth's magnetism is called a *couple*.)

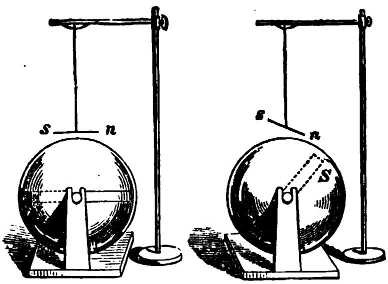


FIG. 171.

253. **The Earth's Magnetic Elements.**—To fully determine the magnetic elements at any point on the earth's surface we must know three things:—

1. The declination (or variation).
2. The dip (or inclination).
3. The intensity of the earth's magnetic force.

The last is the strength of the earth's magnetism at the particular place of observation. This force varies in strength at different places, being least at the magnetic equator, and increasing as we approach the magnetic poles. The direction of this magnetic force is the same as the direction of the dipping-needle. This force, which is inclined to the horizon, may be treated as the resultant of two forces, or may be resolved into two components, the one horizontal and the other vertical. But it is sufficient to measure only the horizontal intensity, i.e. the intensity of the force in a horizontal direction. For if we know the horizontal intensity and the angle of dip, it is easy to calculate the total intensity. (Horizontal intensity = total intensity × cosine of dip.)

Magnetic Instruments.—The instruments for the purposes of observing these magnetic elements are three:—

1. The declinometer, to measure the declination.
2. The dip-circle to measure the dip.
3. The horizontal force magnetometer, to measure the horizontal intensity.

The Declinometer.—This instrument consists of a magnetised needle *a b* (see fig. 172) capable of turning about its centre, which is suspended on a vertical pivot placed at the centre of a carefully graduated card, N M O E. A telescope, L, is capable of turning about the horizontal axis X, and its centre is vertically over the pivot of the needle. The graduated circle Q R and the vernier V indicate the horizontal angle through which the telescope is swept round; whilst the graduated arc *x* and the vernier K indicate the inclination of the telescope to the horizon. The pillar P supports the instrument on its triangular foot, through which pass the levelling-screws

screws are adjusted till the spirit-level *n* indicates that the instrument is level. Of course all the fittings are of brass and iron being included, as it would affect the magnetic needle. *declinometer* the compass and its card are to be made level by crews S S and the spirit-level *n*. The telescope is then pointed nomical meridian, either by pointing at the sun at midday, or ell-known astronomical means. Its position, as shown by the s then read. Then the telescope is turned round to be parallel le, which is done by tilting it so that the point of the needle wed through it. Its new position is again read by its vernier, V. nce between the two readings is the angle which the magnetic kes with the true meridian, i.e. it is the required declination

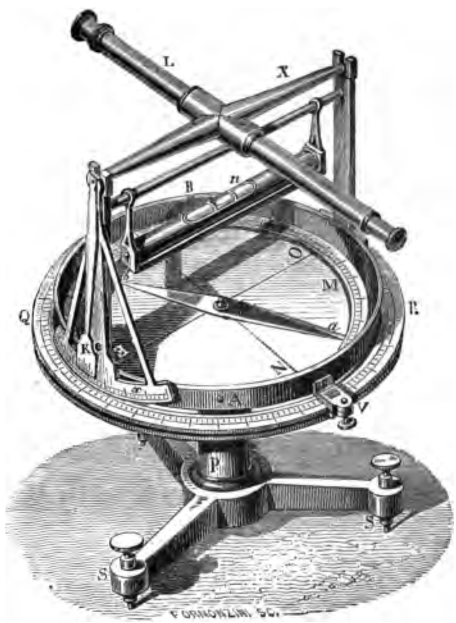


FIG. 172.

he **Dip Circle**, as used in magnetic observatories, is a very it complicated instrument. The accompanying figure represents nple form of the dip-circle. This consists of a needle capable in a vertical plane about a horizontal axis. The needle lies vo circular plates of glass which support its horizontal axis. A rass carefully graduated surrounds the needle, so that its points ithin the graduations. On the needle are certain brass balls slide on small rods. These are so adjusted that the needle,

before magnetisation, will swing on its axis, exactly horizontal. Then, *after magnetisation*, it will dip in the true direction. The vertical circle can be readily turned round the axis which supports it on the horizontal foot. *To use the instrument* it is first levelled by means of its levelling-screws in the foot and the spirit-level. The graduation 90° is then vertically below the axis of the needle, and the graduation 0° on a horizontal level with that axis. The vertical circle must then be turned round so as to lie exactly in the magnetic meridian. The usual method of doing this is to first turn the vertical circle round till the needle dips down vertically. This it does when its plane is magnetic east and west. For then the north horizontal force can have no effect on the needle, but the vertical component of the force alone exerts its effect, so that the needle stands upright. Having thus got the magnetic east and west, turn the vertical needle round through 90° and we get the magnetic north and south, i.e. the vertical plane is then in the magnetic meridian. In this position the angle which the needle makes with the horizontal, as shown by the graduated arc, is the required angle of dip. In actual use, readings are taken at both ends of the needle. Then the vertical circle is turned round through 180°, and readings again taken at both ends of the needle. By taking the mean of such pairs of readings, many errors in the construction of the instrument are avoided.

FIG 173.

255. **Magnetometer. Measurement of Horizontal Force.**—The instrument used for measuring the horizontal force is the *Unifilar Magnetometer.* It consists of a steel bar of rectangular shape so that its mass and dimensions can readily be calculated. This bar is carefully magnetised and hung by a single fibre, hence its name. The fibre being so fine that its torsional elasticity may be neglected, the bar is perfectly free to swing. The process of determining the horizontal force is twofold :—

1. Observations of the time of the swing of the bar magnet under the influence of the earth's magnetism.

2. Observations of the deflection caused by this bar magnet on a small magnetic needle placed near it.

Without entering into the detail of these two processes we can indicate their general methods. When the suspended bar magnet is twisted round in a horizontal plane from its resting position of north and south, on being set free it will oscillate backwards and forwards through its resting position. These horizontal oscillations are similar to the vertical oscillations of a suspended pendulum, and in both cases the square of the number of oscillations in a given time is proportional to the force which causes them. In our case the force causing them is a magnetic one and is usually written H.*m*. In this product, H stands for our required horizontal force, and *m* is the magnetic moment of the magnet, i.e. the length of the magnet multi-

plied by the strength (expressed in proper units) of one of its poles. Let us observe then the number of oscillations in a given time, or the time of a single oscillation, and we can deduce a result $H m. = A$, where A is some known quantity. But we do not want the product $H.m$, we want H alone. To obtain it we make use of the deflection method. For this purpose, the same bar-magnet is made use of to cause a deflection in a small compass-needle. The bar-magnet lies pointing east and west, with its centre south of the small needle. Then the unlike poles of the two magnets attract each other, the like poles repel, so that the compass needle is deflected from its true position of north and south. The angle of deflection δ is noted, and the distance r from the centre of the needle to each of the poles of the deflecting bar-magnet. Then the ratio $\frac{H}{m}$ can be proved equal to $\frac{1}{r^3 \tan \delta}$. For simplicity let B stand for this known fraction. Then we have two relations connecting H and m, viz.

$$\left.\begin{aligned} H.m &= A \\ \frac{H}{m} &= B \end{aligned}\right\}$$

where A and B are both known, and of course their product also is known. Multiply the corresponding sides of these two equations together and we have

$$H.m \times \frac{H}{m} = AB$$

$$\text{or } H^2 = AB$$

$$H = \sqrt{AB}$$

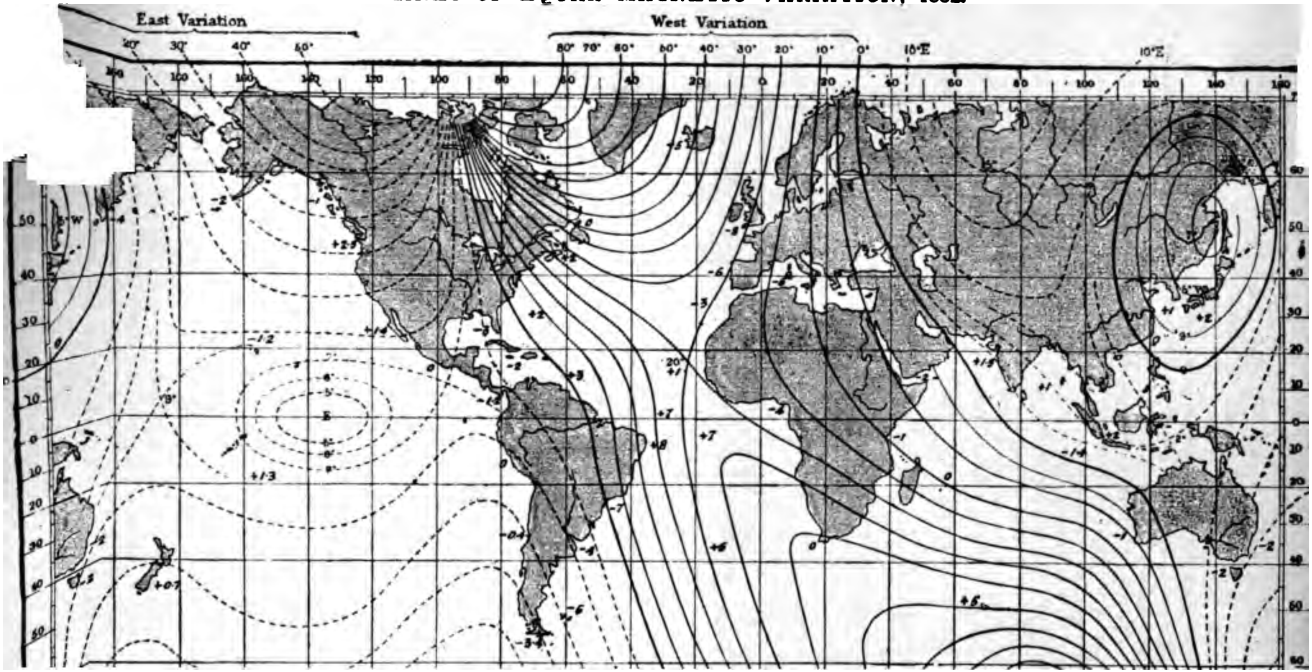
This gives H the required horizontal force. If the total force is wanted, it can be deduced when we know the angle of dip; for,

Horizontal force = total force × cos (angle of dip).

By the use of such instruments as have been described, the data are obtained from which magnetic maps are constructed, i.e. maps in which lines are drawn indicating the magnetic elements at different places. These lines have various names.

256. **Isogonic Lines** are lines drawn through all places which have the same declination (or variation). A map of these lines is given, and we take the following examples from it. Thus the isogonic line for 20° west declination passes through England in an oblique direction, touches Brittany and the north-east corner of Spain, and passes down the Atlantic Ocean. One of the lines showing no variation, the *agonic line*, passes from the north-east corner of North America, through Hudson Bay, through Lake Huron, past the West Indies, through Brazil, into the South Atlantic. The course of another line of no variation can be similarly traced from Lapland down to Australia. There is a third line of no variation which forms an oval in the eastern portion of Asia. These lines are more complicated than might be expected, and show that the distribution of the earth's magnetism is by no means simple. More will be said on this after describing the other magnetic lines. (The figures on the map on page 290 preceded by the sign + or – show the *approximate annual* increase or decrease of declination in minutes of arc.)

LINES OF EQUAL MAGNETIC VARIATION, 1882.



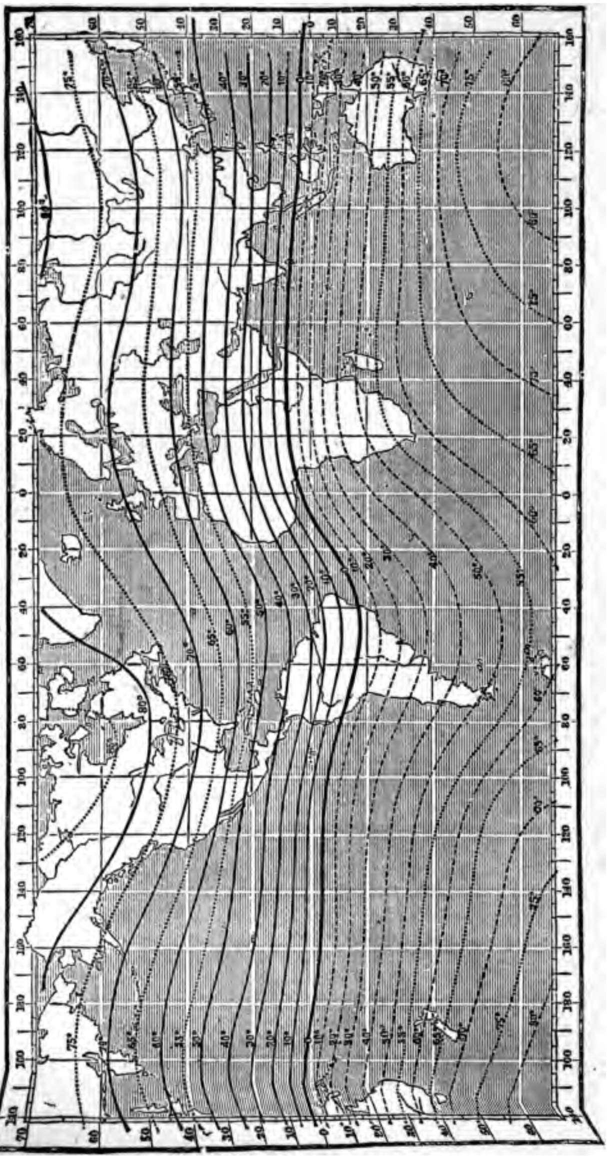
257. Isoclinic Lines are lines drawn through places which have the same inclination or dip. These lines are not so irregular as the isogonic lines, but form wavy curves round the earth, which are not very far from circles. The course of several can be traced out from the map given. The *magnetic equator*, or *aclinic line*, is that line which passes through places which have no dip. Its course may be followed from the map, and it will be observed to keep in equatorial regions, and to cross the geographical equator four times. The magnetic poles are the two positions in the northern and southern hemispheres where the needle dips vertically. It may help the student to think of these two sets of magnetic lines, isogonics and isoclinics, as somewhat like the two sets of geographical lines, longitude and latitude.

258. Lines of Equal Intensity, or isodynamic lines, are lines drawn through all places on the earth's surface at which the intensity of the earth's magnetism is the same. As it is usually only the horizontal intensity which is actually measured, maps are drawn for lines of equal horizontal intensity.

259. Distribution of the Earth's Magnetism.—By comparing such maps given for isogonic and isoclinic lines, much has been learnt regarding the distribution of the earth's magnetism. Thus in the map of isogonic lines, we have noticed that there are three lines of no declination. These three lines divide the earth into four spaces, in two of which the declination is to the east, and in two to the west. Thus, starting from the Atlantic Ocean, and travelling round the earth at about latitude 40° N., we shall cross these four spaces. First we shall start in a space of west declination; as we approach Eastern Europe, this western declination decreases, till it is finally 0°. Then we cross this line, and in Western Asia have space 2, in which there is eastern declination. This increases for a time, and then decreases, till we come to the oval line of no declination in Eastern Asia. Inside this line, in Japan and Eastern Asia, we have our space 3, with western declination. Then we get again across the oval line of no declination, and, entering the Pacific, get into space 4, with eastern declination, which extends all across the Pacific and most of North America. Thus our four spaces, separated by lines of no declination, are :—

1. Atlantic, and most of Europe; West Declination.
2. Western Asia; East Declination.
3. Japan, and Eastern Asia; West Declination.
4. The Pacific and most of North America; East Declination.

The explanation of these variations is that there are two north magnetic poles, one in the north of North America and the other in the north of Siberia, the American pole being the stronger of the two. The application to the case of our imaginary journey round the earth is simple. In the Atlantic, the American pole is the stronger and pulls the needle to the west. As we approach Eastern Europe, we approach the weak Siberian pole, and recede from the strong American pole, till we get to the line of no variation, when the poles balance one another. Then in crossing Western Asia, the near Siberian pole overcomes the American tendency and pulls the needle to the east. Then we come to the oval line of no declination; and here we are south of the Siberian pole, and the American pole, about 180° in longitude distant, is on the opposite side of the north geographical pole, so that both magnetic poles pull the needle north. Inside the oval we are still near the Siberian pole, but it is now to our west and pulls the needle to the west. The other boundary of the oval is the place where the western pull of the Siberian pole is equal to the



LINES OF EQUAL MAGNETIC DIP.

eastern pull of the American pole; so that there is no declination. Passing on into the Pacific, we approach the strong American pole, which gives our needle an east declination across the whole of the Pacific Ocean. Then crossing America we come to the line of no declination, which extends southwards from this American pole; and where the needle points north, because both the American pole and the Siberian pole, which is 180° away, pull it north. Beyond this line we again enter our first space in the Atlantic of western declination. It will be noticed that the spaces in which the American pole may be said to be dominant, are the larger ones; hence we infer its greater strength. Similar considerations apply to the southern hemisphere, but there it is found that the two magnetic poles are much closer together. This argument is supported by the measurements of the total intensity. By them it is found that there are *two foci of maximum force*, one in Northern America, and one in Northern Asia, the former being the stronger. These foci of maximum force are the points we have been speaking of in the above as the American and Siberian poles. It is better to keep the term pole for another point we shall indicate shortly, and we speak then of four foci of maximum force, two in the northern hemisphere and two in the southern. Their positions, as given by Sir Frederick Evans, and as shown on maps of total force, are:—

American (stronger) focus, 52° N. and 90° W.
Siberian (weaker) focus, 70° N. and 115° E.
Stronger Southern focus, 65° S. and 140° E.
Weaker Southern focus, 50° S. and 130° E.

We will now make it quite clear what is meant by north magnetic and south magnetic pole. From the map of equal variation, it will be observed that the lines converge to a point in the extreme north of North America. This point is considerably to the north of the American focus, and, in fact, is between the American and Siberian foci. It has been reached by Sir James Ross, in 1831, and not only do the lines of equal variation converge to that point, but its position is indicated by the fact that there the dipping-needle dips vertically. This pole of verticity is generally called the north magnetic pole. It is the peninsula of Boothia Felix, at 70° 5′ N., and 96° 43′ W. The similar south magnetic pole, where the south-seeking end of the needle would dip down vertically, is probably at 23° 30′ S., and 147° 30′ E.

260. Variations in the Earth's Magnetism.—It is found, on keeping records of the three magnetic elements, that the earth's magnetism is undergoing continual changes. In magnetic observatories, special self-recording instruments keep a continual account of all these variations. From them, three kinds have been distinguished, viz.:—

1. Secular. 2. Annual. 3. Diurnal Variations.

261. Secular Variations are changes which require many years to run their full course, but sufficient observations have not yet been made to determine with certainty the period of these secular changes. The first record of the *declination* shows that the compass pointed, at London, about 11° east of the true north in 1580. Later observations showed that this easterly declination was decreasing, and in 1657 the needle pointed to the geographical pole. It then began to move westward, reaching its maximum, 24° 38′, in 1818. After this time the westerly declination diminished, and the rate of decrease is in England about 7′ each year. At this rate it

will again point to the true north in 1976. The ***inclination*** also passes through a cycle of changes, as will be seen from the following table.

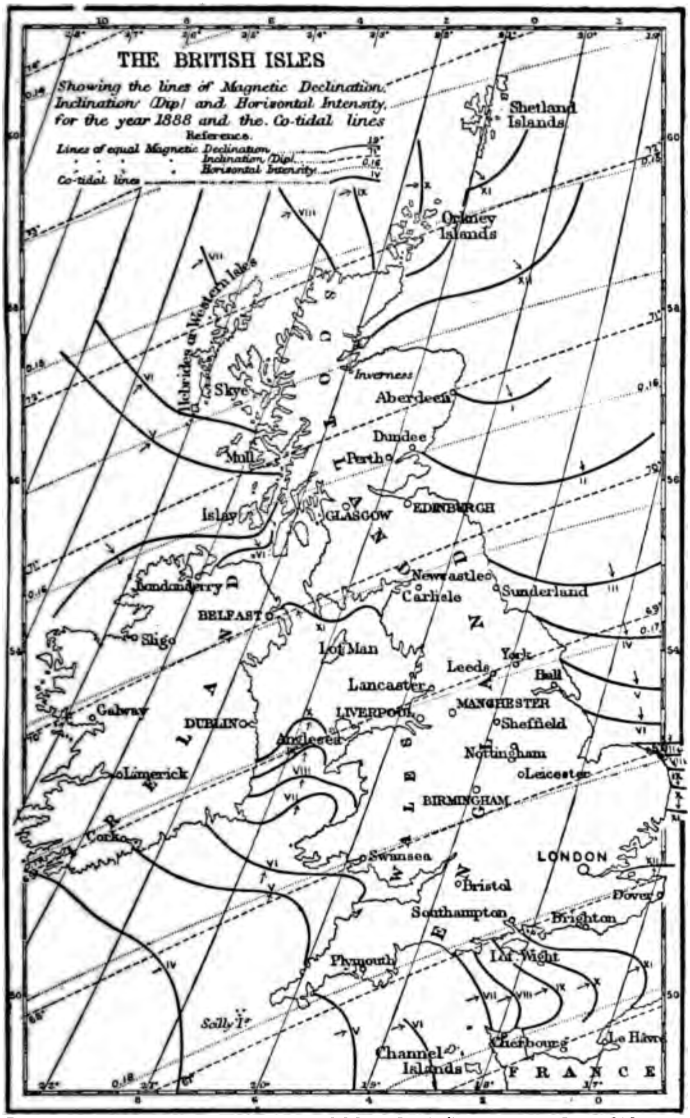
Table of Secular Magnetic Variations at London.

Year	Declination	Inclination
1580	11° 17′ E.	—
1600	—	72° 0′
1622	6° 12′	—
1634	4° 0′	—
1657	0° 0′ min.	—
1676	3° 0′ W.	73° 30′
1705	9° 0′	—
1720	13° 0′	74° 32′ max.
1760	19° 30′	—
1780	—	72° 8′
1800	24° 6′	70° 35′
1818	24° 38′	—
1830	24° 2′	69° 3′
1855	23° 0′	—
1868	20° 33′	68° 2′
1878	19° 14′	67° 43′
1880	18° 40′	67° 40′
1889	17° 35′	67° 25′

The total intensity of the magnetic force exhibits similar secular variations. In London, in 1848 it was ·4791 units, in 1866 it was ·4740, and in 1880 it was ·4736 units.

262. **Annual Variations.**—A change in the magnetic elements occurs at different parts of the year, and these annual variations appear to correspond with the movement of the earth round the sun. The declination in England is greatest about the vernal equinox, and least at the end of June, the difference being 15′ to 18′. The angle of dip is less during summer than the rest of the year. In the British Islands too, the total magnetic force is greatest in June and least in February, the reverse being the case in Australasia.

263. **Diurnal Variations.**—Small oscillations of the needle occur during certain hours of the day, and these small daily variations (a few seconds of arc) require delicate instruments for their observation. In our islands the north pole moves every day westward from sunrise to one o'clock; it then slowly travels back eastward until it regains its original position about ten o'clock. During the night it remains stationary, except in summer, when a slight westward tendency is manifest about midnight. Every eleven years the mean amount of the diurnal variation of the magnetic needle is larger than at other times, and, as already explained, par. 83, these years of maximum variation are also years of maximum sun-spot frequency, and *vice versâ*. How closely the mean daily variation in the magnetic needle during any year corresponds with the amount of sun-spots is shown in fig. 80. A similar periodicity in the recurrence of auroræ also appears to prevail. ('El. Phys.' 289.)



TIDES.—*The lines drawn across the sea are co-tidal lines, that is lines connecting places which have full tide at the same time. The Roman numerals state the number of hours that elapse between the passage of the moon across the meridian at the mouth of the English Channel and the time of full tide at the respective lines. The arrows show the direction of the advance of the tidal wave.*

264. **Magnetic Storms.**—Besides these regular variations in the magnetic needle, sudden irregular, slight disturbances occasionally affect all the compass needles over a great part of the earth. Such magnetic storms are usually accompanied by a display of aurora and by disturbances in the feeble electric currents that are continually traversing the earth from the poles to the equator. It is not yet determined whether these earth currents are caused by the variations in the earth's magnetism, or whether the variations are due to the currents.

265. **Magnetic Observatories.**—At Kew and other magnetic observatories the different magnetic variations are registered by self-recording apparatus. Very sensitive instruments have a light mirror so attached to the magnet that a beam of light sent from the mirror is reflected upon a strip of sensitive photographic paper placed on a revolving drum. This drum is rotated uniformly by clockwork, and when the magnet is at rest the spot of reflected light simply traces a straight line on the paper as the drum rotates. When the magnet moves, however, the spot of reflected light traces out a curved or crooked line, from which the amount of angular deflection can be calculated. Such photographic records are called 'magnetographs,' and the examination of these records, taken at different stations, is likely to be of great service in inquiries as to the origin and cause of the earth's magnetism and its periodic changes. That the earth contains a considerable mass of iron and other magnetic substances there is little doubt, seeing that the interior density must be considerably more than that of the crust, but why this magnetic material should be magnetised is not very clear. The sun's action cannot be direct, for to have such a direct influence its magnetism would have to be enormous. But it might have an indirect influence. Its heat might alter the strain of the earth, and this alteration might disturb the magnetic system. Or the changes might be due to the circulation in the earth's atmosphere, and these changes would then have a maximum when the sun's heat has a maximum, that is, when its surface is most disturbed by sun-spots. Some authorities believe that the chief causes of secular variation must be looked for within the globe itself rather than in solar or extra-terrestrial influences.

266. The map on page 295 shows the value of the magnetic elements in the British Isles during 1888. It will be noticed that the declination west of the eastern agonic line increases by about 30′ for every degree of longitude as we pass westwards from London. Yet there are irregularities in the increase caused by local disturbances of the magnetic needle near lines of great geological faults, and near mountainous masses whose rocks contain magnetite (magnetic oxide of iron). Thus the dioritic rocks of the Malvern Hills are found to affect the north pole of the magnet, and to cause the declination to be in excess on the east side, and in defect on the west side. In the same way some islands are found to affect the compass, and to behave as though they were magnetised in the same way as the hemisphere in which they are situated. It has been proved that these local magnetic disturbances are due to the direct magnetic action of the rocks, and not to the feeble electric currents, known as *earth-currents*, which may be flowing through them. The map also shows how the dip of the needle and the horizontal magnetic force vary as we pass north.

CHAPTER XVII.

COSMOGONY—SECULAR COOLING OF THE EARTH—SECULAR CHANGES OF CLIMATE.

267. **Kant's Hypothesis.**—Cosmogonies (Gr. *kosmos*, the world or universe, and *genō*, to produce), or theories of the origin of the world, the solar system, or the whole universe, were invented by Greek poets and philosophers in very early times. Of these we have not space to speak. The earliest ideas about the growth of worlds in which a knowledge of the Newtonian theory of gravitation and the planetary system plays a part, is contained in an essay issued in 1775 by Emmanuel Kant, who was born at Königsberg in 1724. The essay was entitled 'A General Natural History and Theory of the Heavens.' In the second part Kant treats 'of the first state of nature, the formation of the celestial bodies, the causes of their movement and systematic connection, not merely in the planetary sphere, but in creation as a whole.' Taking the development of the solar system as an instance of a process continually repeating itself in the universe, he supposes that 'all the materials out of which the bodies of our solar system were formed, were, in the beginning of things, dissipated in their original elements, and filled all the space of the universe in which these bodies now move.' This gaseous mass was in a state of chaos, and its elementary molecules were endowed with forces of attraction and repulsion. But the denser particles of the mass began to gather round them the rarer particles, the central nucleus became the sun; extended ranges or strata of revolving matter, decreasing in density from the centre, arose from movement set up by the attraction of the central mass, and the repulsion between the particles. In these strata local nuclei formed and gave origin to the planets, some with satellites; and thus the original chaotic mass gave place to the system we see. 'If we examine the result of this hypothesis,' says Professor Newcomb, 'by the light of modern science, we shall readily see that all the bodies thus formed would be drawn to a common centre, and thus we should have, not a collection of bodies like the solar system, but a single sun formed by the combination of them all. In attempting to show how the smaller masses would be led to circulate around the larger ones in circular orbits, Kant's reasoning ceases to be satisfactory. He seems to think that the motion of rotation could be produced indirectly by the repulsive forces acting among the rarer masses of the condensing matter, which would give rise to a whirling motion. But the laws of mechanics show that the sum total of rotary motion in a system can never be increased or diminished by the mutual action of its separate parts, so that the present rotary motions of the sun and planets must be the equivalent of that which they had from the beginning.' The fixed stars were also regarded by Kant as forming a system aggregated in the plane of the Milky Way, the movements of this star-system being regulated by a great central star. The nebulæ were also regarded as forming other stellar systems, and Kant even suggests a central body controlling all the systems that exist in the infinitude of space. Modern astronomy knows nothing of such great central bodies.

268. **Laplace's Nebular Hypothesis.**—Without any knowledge of the ideas of Kant, Laplace gave, at the close of his 'Système du Monde'

(Paris, 1835), a physical explanation of the origin of the solar system, which is known as the 'Nebular Hypothesis.' He pointed out (1) that the planets of the solar system all revolve round the sun in one direction, from W. to E.; (2) that this revolution round the sun was nearly in the same plane as that of the solar system; (3) that the revolution of the satellites was in the same direction as that of the planets; (4) that the sun, planets, and satellites rotate on their axes in the same direction as the general revolution round the sun; (5) that the orbits of revolution of the planets and satellites are nearly circular; (6) and that the phenomena of Saturn's rings are suggestive of a mode of planetary origin. The uniformity of revolution and rotation in the solar system must have risen from some primary and common cause; for the chances against such uniformity being a mere coincidence or the result of accident, would be as four millions to one. Laplace, therefore, conceived the hypothesis: (1) that the matter now collected in the sun and planets once existed as a nebulous mass of intensely heated gas, filling the space beyond that occupied by the solar system;

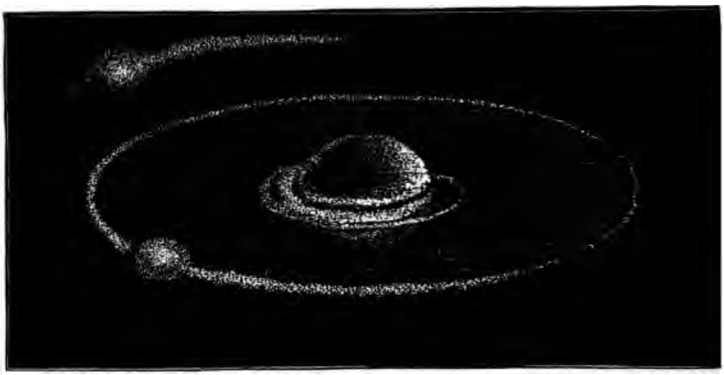


FIG. 174.—Illustration of Nebular Hypothesis.

(2) that in the primitive state of the sun its atmosphere extended beyond the orbits of all the planets, the sun forming the brighter nucleus; (3) that this immense vaporous mass had a slow rotation on its axis, in consequence of which, during the contraction of the mass under the action of its own gravitation, the rotation would be accelerated; (4) that the time would therefore arrive when the centrifugal force at the equator of the rotating mass would become equal to that of gravity, and rings of nebulous matter would be left behind, resembling the rings of Saturn; (5) that these rings, after revolving for a time as a whole, would gather into a single globe, which would continue to revolve round the central mass. Fig. 174 is an attempt to represent the birth of planets according to Laplace's theory; but a better illustration of an early stage in planetary development may possibly be furnished by Mr. Roberts's recent photograph of the great nebula in Andromeda, where we probably see 'a condensed central nucleus, surrounded by a series of flattened rings, the rings being divided from each other by dark spaces or rifts.' (See fig. 159.)

269. Remarks on Laplace's Theory.—Laplace's hypothesis is a narrower one than that of Kant, and is based on a firmer foundation. Kant explained the ring of Saturn as a special case, while Laplace regarded it as the type and foundation of his theory. Laplace put the comets in a class of their own, and regarded them as visitors in the solar system, while Kant endeavoured to include them in his explanation. It is clear that Laplace's hypothesis explains the phenomena of the solar system on which it is based. It is no objection to Laplace's view that there is a zone of small planets between Mars and Jupiter, for he considered it probable that some of the rings would break up into separate masses, each revolving round the sun in its orbit. Nor is it a bar to the acceptance of the nebular hypothesis that Uranus and Neptune have a retrograde rotation. 'If the ring be nearly of the same density throughout, the resulting planet (which would be formed at about the middle of the ring's width), must have a retrograde rotation like Uranus and Neptune. But if the particles of the rings are more closely packed near its inner edge, so that the resulting planet would be formed much within the middle of its path, its axial rotation must be direct.'[1] A real difficulty is the revolution of Phobos in a period less than the period of rotation of Mars (par. 102). Other considerations, however, besides those urged by Laplace, support a nebular hypothesis of some form or other. Among these may be mentioned the much greater density of the four terrestrial planets compared with that of the four exterior planets, the greater density of the earth compared with that of the moon, the increase of temperature as we penetrate deeper into the earth, and the identity of chemical composition of meteorites, the earth, and the sun. It is quite probable that, with some alterations, Laplace's hypothesis comes near the truth, for it satisfies most of the conditions of the problem. One modification has been thought necessary, on considering that the heat of the sun is now mainly produced and maintained by its slow contraction under the force of the enormous gravitative attraction that exists in so large a mass. This appears to dispense with the need of a high temperature in the original nebula, though it does not prove that a high temperature was impossible.

270. Lockyer's Meteoric-Nebular Theory.—Other modifications of Laplace's hypothesis have been made. M. Faye supposes that the planets were formed by local condensations within the primitive revolving nebula, and not from rings shed by the parent mass. He also suggests in his work *Sur l'Origine du Monde*, that the terrestrial group of planets is older than the outer group, and that the earth itself is older than the sun. But the ideas recently put forth by Professor Lockyer, in his meteoric-nebular theory, represent the most important change of view. This theory (already referred to in pars. 221, 231) is based on the spectroscopic examination of meteorites in the laboratory under various circumstances of temperature and pressure, and on the comparison of the spectra thus observed with those of the various kinds of heavenly bodies. As a result, Lockyer holds that the idea which regards nebulæ, stars, and comets as different orders of bodies must be given up, as well as the notion that the 'stars' are all cooling bodies. He maintains that all the self-luminous bodies in space are, or have been, swarms of meteoric dust, that the differences between them are due to the various stages of condensation and aggregation of these meteorites, that some are at present increasing in temperature and some diminishing, the temperature depending on the frequency and violence of the collisions;

[1] Young.

that comets, nebulæ, bright-line stars, and most variables are still composed of multitudes of separate small bodies surrounded by the glowing gases driven off during the collisions; that the sun and such stars as Sirius are globes of incandescent gas formed out of vaporised meteor-swarms, drawn together by the energy of gravitation. We add some of Professor Lockyer's conclusions in his own words:—

'I. All self-luminous bodies in the celestial spaces are composed of meteorites or masses of meteoric vapour produced by heat, brought about by condensation of meteoric swarms due to gravity.

'II. The spectra of all bodies depend upon the heat of the meteorites, produced by collisions, and the average space between the meteorites in the swarm, or, in the case of consolidated swarms, upon the time which has elapsed since complete vaporisation.

'III. The temperature of the vapours produced by collisions in nebulæ, stars without C and F, but with other bright lines, and in comets away from perihelion, is about that of the Bunsen burner.

'IV. The temperature of the vapours produced by collisions in θ Orionis and similar stars is about that of the Bessemer flame. . . .

'VI. The brilliancy of these aggregations at each (increasing) temperature, depends on the number of meteorites in the swarm, i.e. the difference depends upon the quantity, not the intensity of the light.

'VII. The existing distinction between stars, comets, and nebulæ, rests on no physical basis.

'VIII. The main factor in the various spectra produced is the ratio of the interspaces between the meteorites to their incandescent surface. . . .

'XI. New stars, whether seen in connection with the nebulæ or not, are produced by the clash of meteor swarms, the bright lines seen being low temperature lines of elements, the spectra of which are most brilliant at a low stage of heat.

'XII. Most of the variable stars which have been observed belong to those classes of bodies which I now suggest are uncondensed meteor-swarms, or stars in which a central, more or less solid, condensed mass exists. In some of those having regular periods, the variation would seem partly due to swarms of meteorites moving around a bright or dark body, the maximum light occurring at periastron.

'XIII. The spectrum of hydrogen seen in the case of the nebulæ seems to be due to electrical excitation, as happens with the spectrum of carbon in the case of comets. Sudden changes from one spectrum to the other are seen in the glow of meteorites in vacuum-tubes when a current is passing, and the change from H to C can always be brought about by increased heating of the meteorite.

'XIV. Meteorites are formed by the condensation of vapours thrown off by collisions, and this increase may go on until the meteorites may be large enough to be smashed by collisions when the heat of impact is not sufficient to produce volatilisation of the whole mass.

'XV. Beginning with meteorites of average composition, the extreme forms, iron and stony, would in time be produced as a result of collisions.

'XVI. In recorded time there has been no such thing as a "world on fire," or the collision of masses of matter as large as the earth, to say nothing of masses of matter as large as the sun, but the known distribution of meteorites throughout space indicates that such collisions may form an integral part of the economy of nature. The number of bodies, however, subject to such collisions is small, and must, it would appear, form but a small percentage of the celestial bodies, seeing that they must be consolidated.'

Professor Lockyer even ventures to describe the pre-nebular condition of matter. It is matter so fine that it is impossible to give it a chemical name. This matter 'curdles' into a substance which is either hydrogen itself or some substance or substances connected with hydrogen. It is suggested that we have indications of this substance in the mysterious D_3 line of some nebulæ and the solar chromosphere. Further curdling and condensation leads to the production of an exquisitely fine dust which goes on condensing until we get the dust of such substances as magnesium, carbon, oxygen, iron, silicon, and sulphur in addition to hydrogen. Such dust at last becomes agglomerated into meteoric iron and stones. With motion in this fine dust, and gravitation leading to the formation of centres, we get rotation and condensing masses, nebulæ being condensations of meteoric dust. As condensation goes on, collisions between the tiny meteors increase, the temperature rises, and we come to such a central system and spiral surroundings as is shown in Mr. Roberts's Andromeda photograph, or to a variable like Mira, where we may imagine one condensed swarm revolving round a larger one in such a way that there is a periodical encounter between the two swarms when they are nearest together. In some such way Professor Lockyer leads us to the beginning of that temperature curve where he has located the first group of heavenly bodies. How much truth this bold extension and modification of Laplace's hypothesis contains it is impossible yet to say. Certain it is that much spectroscopic evidence is in its favour, though some evidence of this nature is still doubtful; while Professor G. Darwin has shown that the mechanical condition is for some time virtually the same as if the meteoric particles were molecules of a gas.[1]

One fact remains clear as the result of all spectroscopic inquiry. With the possible exception of the existence of some more elemental form of matter in certain nebulæ, and in the hottest region of the sun and stars like Sirius, the earth, meteors, the sun, and all heavenly bodies are constituted alike chemically; a nebula in its gradual passage to the condition of a cold planet showing almost every variety of spectrum observed in the various groups of heavenly bodies.

271. **Internal Temperature of the Earth.**—The temperature of the air at the surface of the earth depends essentially on the heat received by this surface from the sun. Hence it varies at different times of the day according to the altitude of the sun, and for different months or seasons of the year according to the length of the day and the angle at which the solar rays strike the surface. The mode of showing the mean temperature for any period at various latitudes by means of isothermal lines is set forth in the 'El. Phys.' pars. 211–213. The diurnal inequalities of temperature are insensible in the earth's crust beyond a depth of 3 feet, and the annual inequalities also cease to be felt beyond a depth of from 50 to 80 feet. At a certain depth, therefore, depending partly on the nature of the rocks, and partly on the latitude, we reach a point where the seasonal variations cease to operate, and a stratum of *invariable temperature* is reached. This invariable temperature is about the mean annual temperature of the place. At Paris it is at a depth of 92 feet, and the constant temperature is 53° F.; at Greenwich it is found at a depth of 50 feet, where a constant temperature of 45°·5 F. prevails. A surface passing through the points in the earth's crust where the temperature is always the same is called the *invariable stratum*, and the

[1] The recent investigations of Professor Lockyer may be found in the *Proceedings of the Royal Society*, vols. 44 to 48.

depth of this stratum decreases, on the whole, as we pass from the equator to the poles. In Central England the invariable stratum may be taken to have a depth of 50 feet and a temperature of 50° F. Below this invariable stratum the temperature increases the deeper we go. The rate of increase may be taken to be on the average 1° F. for every 50 feet of descent, though in some rocks it is higher than this, and in some cases lower.[1] The fact of this increase, and the rate of increase, have been ascertained by taking the temperature of mines and borings. Special precautions are needed in ascertaining the temperature in a tunnel, a mine, or a boring. It is not sufficient to place thermometers on the rock at certain depths, and read off their indications. The face of the rock is affected by the air in a mine, and some of this has passed down by diffusion from above, or has been forced down by ventilating machinery. Hence self-registering maximum thermometers must be embedded in the coal or other rock at such a distance from the face that the temperature of the rock is unaffected by the air of the mine. A distance of four or five feet from the face is generally found sufficient. In an artesian bore-hole several difficulties present themselves in attempting to ascertain the law of increase in temperature with descent. The boring tool increases the heat of the rock by friction, so that measurements cannot be taken during the progress of the work; and after the work is completed the bore-hole stands nearly full of water. This water is disturbed by convection currents, and the difficulty, therefore, is to make sure that the water in which we place the thermometer is at the temperature of the rock at the same depth. To get rid of these disturbing causes, and especially to shut off convection currents, observations were made in a deep boring (4,172 feet) at Sperenberg, near Berlin, by lowering an apparatus called a *geo-thermometer*,[2] which cuts off a portion of water from that above and below it by two discs or bags. A thermometer was enclosed between the discs and allowed to remain down ten hours. On withdrawing the instrument it is believed that the temperature it registers is the temperature of the rock at a corresponding depth. The results showed a diminished rate of increase in the lower depths, but it has been argued that this diminution was due to the fact that the discs do not completely shut off convection currents, and were not left down long enough. Later and even more careful determinations have been made at Schladebach in Germany, in a bore of greater depth (1,748 mètres) and smaller diameter than that at Sperenberg.

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[1] Professor Prestwich considers the general means to be :—

For coal mines	1° in 49·5 feet.
For mines other than coal . .	1° ,, 43·2 ,,
For artesian wells . . .	1° ,, 50 ,,

[2] These instruments are overflow thermometers, generally without scales, and are enclosed (for protection against pressure) in a hermetically-sealed case of stout glass with an external diameter of 15 mm. To take the reading, the thermometer, after being drawn up, is put with a normal thermometer into a vessel of water at a temperature a little below that expected. Warm water is then gradually added, and the whole kept stirred till the mercury in the overflow thermometer reaches the open end. The temperature at this moment is then read by the other thermometer.

Lines passing through depths of the earth's crust at which the temperature is the same may be called *geo-isotherms*.

Isolated water-columns were obtained by a plugging of moist clay made to press against the sides of the bore instead of by an india-rubber disc as at Sperenberg. The small difference of reading between the thermometer placed in the isolated column and that placed in the open water just above shows that in this narrow bore the effect of convection was very small. 'The series of observations (at Schladebach), extending as it does by regular stages from the surface to a depth of 5,630 feet, in a new bore where there has not been time for the original heat to be lost by exposure, forms undoubtedly the most valuable contribution ever made to the observations of underground temperature.' The observations show neither acceleration nor retardation of rate of increase as the depth increases, and the curve of temperature is best represented by a straight line. The mean rate of increase is equivalent to 1° for every 65 feet of descent. To what depth this rate of increase will continue, we cannot say.[1] 'Nevertheless, it is unquestionable,' says the Rev. O. Fisher, in his work entitled, 'Physics of the Earth's Crust,' 'that there must be a diminution, and that this equable law of increase of temperature, though sensibly true near the surface of the earth, cannot extend to all depths; for if it did, we should have, at a depth of from 200 to 400 miles, temperatures which would equal those which have been, on good authority, attributed to the sun itself. The equable law of increase, however, may be so far depended on as to lead us to expect at most localities a temperature at which the rocks would melt at a depth of certainly less than thirty miles.'

272. **Origin of the Earth's Internal Heat.**—As the internal heat must pass from the interior through the solid crust by conduction, and on reaching the surface pass by radiation into space, we can only conclude that the earth was at one time much hotter, and that it is now, and has been for untold ages, *a cooling globe*. At present, however, 'the escape of heat from the interior, through the external shell of the earth out into the air and free space, must be of most inconceivable slowness, so much that no appreciable share in producing or maintaining the warmth of the *surface* can be attributed to it, and that the difference of climates and local temperatures is the result entirely of external influences.' At the same time, not only do the phenomena of volcanoes and hot springs indicate unmistakably the still further increase of heat beyond the reach of artificial excavation, but the fact itself, that the mean density of the globe is so small as $5\frac{1}{2}$, must be held conclusive evidence of the excessive internal temperature.' These considerations lead us to believe that there was a time when the earth was in a molten condition and that the heat of the interior is a remnant of this primitive state. This fluid condition in the distant past receives support from certain geological phenomena and from the present shape of the earth. A mathematical investigation of the figure of the earth on the hypothesis of a former fluid state makes the ellipticity to be $\frac{1}{293}$, while the geodetic measurements of various meridional arcs, referred to in paragraph 188, give an elipticity of $\frac{1}{293}$. This coincidence of theory and measurement gives strong support to the idea of a pristine molten condition. The nebular hypothesis also lends its support to this view.

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[1] Even in the frozen soil at Jakutsk in Siberia an increase of temperature with increase of depth is found to prevail, and the rate of increase is even, 1° F. for 28 feet. The limit of frozen soil is there 620 feet, the mean temperature at the surface being 12°·7 F.

273. **Primeval Chemistry of the Earth.**—Assuming that the earth was once a part of the primal nebular mass out of which the solar system was evolved, it is certain that if it ever formed a globe of highly heated gas, the heat would then be so great that the various compounds now existing would all be completely dissociated. Water, for example, could not then exist even as a gas, for we know that at very high temperatures it is resolved into hydrogen and oxygen. Even after cooling had so far proceeded as to allow of some combinations, the globe of confined liquefied matter would be enveloped by an atmosphere of dense vapours formed of compounds now forming part of the earth's crust. It would be interesting if we could follow the various stages of condensation in the original globe. Probably some of the most refractory metals were the first to consolidate and now form the core of the earth; these might be followed by such compounds as the highly stable silicates; steam might then be formed in the atmosphere by the oxidation of the hydrogen, but it would exist under a pressure many times greater than that of our present atmosphere. According to Dalton's laws, gases when diffused through each other behave as if they were separate and thus the lighter gases would preponderate into the outer regions of the early atmosphere. We might, therefore, at one period have a zone of such vapours as sodium chloride, above it a zone mainly of CO_2, above this a zone mainly of aqueous vapour mixed with the lighter gases, oxygen and nitrogen. As the cooling went on, the vapour of the salt and other chlorides would condense, and this would be followed by the condensation of some of the aqueous vapour to form the primitive oceans. This is probably not the only source of the salinity of the ocean waters; for although some chlorides may have been formed in the earliest stages of the earth's history by direct combination of the metals, it is also probable that the sodium and potassium dissolved out of the previously formed felspars by carbonated waters and carried down to the sea in the form of soluble carbonates, supply another source. These would be reacted upon by the chlorides of the alkaline earths thus:

$$Na_2CO_3 + CaCl_2 = 2NaCl + CaCO_3.$$

The decomposition of silicates by alkaline carbonates would not be the only source of the carbonates of the earth's crust, for it has been suggested that much of the CO_2 present in early stages would unite with the oxides of the alkalies to form the alkaline carbonates by direct synthetic combination. But the subject is too speculative for us to pursue farther. What is satisfactorily known of geological chemistry will be found in the Appendix.

274. **Present Condition of the Earth's Interior.**—With a globe of molten matter different modes of consolidation are conceivable. But we have not sufficient data to say whether solidification began at the surface or at the centre. We know that the exterior crust is solid, but we are ignorant of its thickness, and of the state of matter a few miles below the surface. It must, however, now have one of the three following constitutions.

1. The earth may consist of a solid crust with a fluid interior.
2. It may consist of a solid nucleus in the centre and an external solid crust, separated by a fluid shell.
3. It may be solid throughout.

It may be thought that the increase of temperature as we descend into the interior must result in the fusion of the rocks at a certain depth, and that the idea of a fluid interior is therefore correct. But we must bear in mind that there is reason to believe that the rate of increase gradually

diminishes beyond a certain depth (100,000 feet according to Sir William Thomson) and we know that the fusing-point of solids rises with increase of pressure. It is, therefore, quite possible that the enormous pressure keeps the imprisoned rocks in a state of compulsory solidity, and that the interior is potentially molten, though really solid. Such a condition accounts, according to some authors, for most volcanic phenomena. In a space relieved of the superincumbent pressure the rock assumes the liquid condition, and the shrinkage due to cooling is often forming such spaces and leading to volcanic and earthquake phenomena. A further argument against a fluid interior and a thin solid crust is urged by Sir William Thomson. A thin shell would be so disturbed by the tidal influence of the sun and moon on the liquid interior that the distortion produced would be capable of detection by direct measurement in the tides on the surface. No such effect has been observed. As a result of his mathematical investigations Sir William Thomson concludes that the earth is nearly as rigid as steel. On the other hand the Rev. O. Fisher maintains that the result of both mathematical and geological inquiry is to show that there is a liquid substratum holding gases in solution beneath the crust, the mountains having roots of unmelted lighter material projecting into a heavier molten liquid, and the permanent sub-oceanic crust dipping more deeply into the substratum than the continental crust. As to the density of the interior we do know something definite. The mean density of the surface rocks is found by actual observation to be about 2·6. The mean density of the whole earth has been determined, by experiments with the plumb-line and the torsion-balance, to be about 5·5. It follows, therefore, that the interior must consist of matter of higher specific gravity than that forming the crust. According to the law assumed by Laplace in calculating the ellipticity of the earth, the increase of the square of the density is proportional to the increase of the pressure. Employing this law to calculate the density at various depths, on the supposition that the interior consists of layers increasing in density towards the centre, we find a density of 3·8 at a depth of 500 miles, a density of 4·8 at 1,000 miles, a density of 7·5 at 2,000 miles, and a density of 9·8 at the centre. This high density of the interior is most probably due to the larger percentage of heavy metals there; for it is not likely that the density of such rocks as we find near the surface can be increased to the extent required, by any amount of pressure, though some increase of density will be due to this cause.

275. An address on 'The Mathematical Theories of the Earth,' delivered by Professor R. S. Woodward before the American Association for the Advancement of Science, at Toronto, in August last, contains such admirable remarks on some of the subjects alluded to in the preceding paragraphs, that no apology is needed for making the following quotations:—

'All of the principal mechanical properties and effects of the earth's mass, viz., the ellipticity, the surface density, the mean density, the precession constant, and the lunar inequalities, were correlated by Laplace in a single hypothesis, involving only one assumption in addition to that of original fluidity and the law of gravitation. This assumption relates to the compressibility of matter, and asserts that the ratio of the increment of pressure to the increment of density is proportional to the density. Many interesting and striking conclusions follow readily from this hypothesis, but the most interesting and important are those relative to density and pressure, especially the latter, whose dominance as a factor in the mechanics of celestial masses seems destined to survive whether the

hypothesis stands or falls. The hypothesis requires that while the density increases slowly from something less than 3 at the surface to about 11 at the centre of the earth, the pressure within the mass increases rapidly below the surface, reaching a value surpassing the crushing strength of steel at the depth of a few miles, and amounting at the centre to no less than three million atmospheres. The inferences, then, as distinguished from the facts, are that the mass of the earth is very nearly symmetrically disposed about its centre of gravity, that pressure and density, except near the surface, are mutually dependent, and that the earth in reaching this stage, has passed through the fluid or quasi-fluid state.

'Later writers have suggested other hypotheses for a continuous distribution of the earth's mass, but none of them can be said to rival the hypothesis of Laplace. Their defects lie either in not postulating a direct connection between density and pressure, or in postulating a connection which implies extreme or impossible values for these and other mechanical properties of the mass.

'It is clear from the positiveness of his language in frequent allusions to this conception of the earth, that Laplace was deeply impressed with its essential correctness. "Observations," he says, "prove incontestably that the densities of the strata [*couches*] of the terrestrial spheroid increase from the surface to the centre;" and "the regularity with which the observed variation in length of a seconds pendulum follows the law of the squares of the sines of the latitudes, proves that the strata are arranged symmetrically about the centre of gravity of the earth." The more recent investigations of Stokes, to which allusion has already been made, forbid our entertaining anything like so confident an opinion of the earth's primitive fluidity or of a symmetrical and continuous arrangement of its strata. But, though it must be said that the sufficiency of Laplace's arguments has been seriously impugned, we can hardly think the probability of the correctness of his conclusions has been proportionately diminished.

'Suppose, however, that we reject the idea of original fluidity. Would not a rotating mass of the size of the earth assume finally the same aspects and properties presented by our planet? Would not pressure and centrifugal force suffice to bring about a central condensation and a symmetrical arrangement of strata similar at least to that required by the Laplacian hypothesis? Categorical answers to these questions cannot be given. But whatever may have been the antecedent condition of the earth's mass, the conclusion seems unavoidable that at no great depth the pressure is sufficient to break down the structural characteristics of all known substances, and hence to produce viscous flow whenever and wherever the stress difference exceeds a certain limit, which cannot be large in comparison with the pressure.

. . . . . .

'Of those who in the present generation have contributed to our knowledge and stimulated the investigation of this subject, it is hardly necessary to say that we owe most to Sir William Thomson. He has made the question of terrestrial temperatures highly attractive and instructive to astronomers and mathematicians, and not less warmly interesting to geologists and paleontologists. Whether we are prepared to accept his conclusions or not, we must all acknowledge our indebtedness to the contributions of his master hand in this field as well as in most other fields of terrestrial physics. The contribution of special interest to us in this connection is his remarkable memoir on the secular cooling of the earth. In this memoir he

adopts the simple hypothesis of a solid sphere whose thermal properties remain invariable while it cools by conduction from an initial state of uniform temperature, and draws therefrom certain striking limitations on geologic time. Many geologists were startled by these limitations, and geologic thought and opinion have since been widely influenced by them. It will be of interest, therefore, to state a little more fully and clearly the grounds from which his arguments proceed. Conceive a sphere, having a uniform temperature initially, to cool in a medium which instantly dissipates all heat brought by conduction to its surface, thus keeping the surface at a constant temperature. Suppose we have given the initial excess of the sphere's temperature over that of the medium. Suppose also that the capacity of the mass of the sphere for diffusion of heat is known, and known to remain invariable during the process of cooling. This capacity is called diffusivity, and is a constant which can be observed. Then from these data the distribution of temperature at any future time can be assigned, and hence also the rate of temperature-increase, or the temperature-gradient, from the surface towards the centre of the sphere can be computed. It is tolerably certain that the heat conducted from the interior to the surface of the earth does not set up any reaction which in any sensible degree retards the process of cooling. It escapes so freely that, for practical purposes, we may say it is instantly dissipated. Hence if we can assume that the earth had a specified uniform temperature at the initial epoch, and can assume its diffusivity to remain constant, the whole history of cooling is known as soon as we determine the diffusivity and the temperature-gradient at any point. Now Sir William Thomson determined a value for the diffusivity from measurements of the seasonal variations of underground temperatures, and numerous observations of the increase of temperature with depth below the earth's surface gave an average value for the temperature gradient. From these elements and from an assumed initial temperature of 7,000°, he infers that geologic time is limited to something between twenty million and four hundred million years. He says: "We must allow very wide limits in such an estimate as I have attempted to make; but I think we may with much probability say that the consolidation cannot have taken place less than twenty million years ago, or we should have more underground heat than we actually have, nor more than four hundred million years ago, or we should not have so much as the least observed underground increment of temperature. That is to say, I conclude that Leibnitz's epoch of emergence of the *consistentior status* was probably between those dates." These conclusions were announced twenty-seven years ago, and were republished without modification in 1883.

. . . .

'When we pass from the restricted domain of quantitative results concerning geologic time to the freer domain of qualitative results of a general character, the contractional theory of the earth may be said to still lead all others, though it seems destined to require more or less modification, if not to be relegated to a place of secondary importance. Old as is the notion that the great surface-irregularities of the earth are but the outward evidence of a crumpling crust, it is only recently that this notion has been subjected to mathematical analysis on anything like a rational basis. About three years ago Mr. T. Mellard Reade announced the doctrine that the earth's crust, from the joint effect of its heat and gravitation, should behave in a way *somewhat* analogous to a bent beam, and should possess

at a certain depth a "level of no strain," corresponding to the neutral surface in a beam. Above the level of no strain, according to this doctrine, the strata will be subjected to compression, and will undergo crumpling, while below that level the tendency of the strata to crack and part is overcome by pressure which produces what Reade calls "compressive extension," thus keeping the nucleus compact and continuous. A little later the same idea was worked out independently by Mr. Charles Davison, and it has since received elaborate mathematical treatment at the hands of Darwin, Fisher, and others. The doctrine requires for its application a competent theory of cooling, and hence cannot be depended on at present to give anything better than a general idea of the mechanics of crumpling and a rough estimate of the magnitudes of the resulting effects. Using Thomson's hypothesis, it appears that the stratum of no strain moves downward from the surface of the earth at a nearly constant rate during the earlier stages of cooling, but more slowly during later stages. Its depth is independent of the initial temperature of the earth; and if we adopt Thomson's value of the diffusivity, it will be about two and a third miles below the surface in a hundred million years from the beginning of cooling, and a little more than fourteen miles below the surface in seven hundred million years. The most important inference from this theory is that the geological effects of secular cooling will be confined for a very long time to a comparatively thin crust. Thus, if the earth is a hundred million years old, crumpling should not extend much deeper than two miles. A test to which the theory has been subjected, and one which some consider crucial against it, is the volumetric amount of crumpling shown by the earth at the present time. This is a difficult quantity to estimate, but it appears to be much greater than the theory alone can account for.

'The opponents of the contractional theory of the earth, believing it quantitatively insufficient, have recently revived and elaborated an idea first suggested by Babbage and Herschel in explanation of the greater folds and movements of the crust. This idea figures the crust as being in a state bordering on hydrostatic equilibrium, which cannot be greatly disturbed without a readjustment and consequent movement of the masses involved. According to this view, the transfer of any considerable load from one area to another is followed sooner or later by a depression over the loaded area and a corresponding elevation over the unloaded one; and in a general way it is inferred that the elevation of continental areas tends to keep pace with erosion. The process by which this balance is maintained has been called "isostacy," and the crust is said to be in an isostatic state. The dynamics of the superficial strata, with the attendant phenomena of folding and faulting, are thus referred to gravitation alone, or to gravitation and whatever opposing force the rigidity of the strata may offer. In a mathematical sense, however, the theory of isostacy is in a less satisfactory state than the theory of contraction. As yet we can see only that isostacy is an efficient cause if once set in action; but how it is started, and to what extent it is adequate, remains to be determined. Moreover, isostacy alone does not seem to meet the requirements of geological continuity, for it tends rapidly towards stable equilibrium, and the crust ought therefore to reach a state of repose early in geologic time. But there is no evidence that such a state has been attained, and but little if any evidence of diminished activity in crustal movements during recent geologic time. Hence we infer that isostacy is competent only on the supposition that it is kept in action by some other cause tending constantly to disturb

the equilibrium which would otherwise result. Such a cause is found in secular contraction, and it is not improbable that these two seemingly divergent theories are really supplementary.'

276. **Secular Changes of Climate.**—The rocks of the earth's crust furnish clear evidence that the climate of the same region has undergone great changes. There is, in the first place, the evidence derived from the fossils found in the rocks of certain regions. In Greenland, Spitzbergen, and other Arctic countries, for instance, where the cold is now so great that no forest-tree can possibly live, we find, in the rocks of the Miocene Tertiary Period, the fossil remains of poplars, beeches, oaks, and other trees which grow only in temperate regions. About the same period we learn, in a similar way, that plants of a sub-tropical nature grew in England and Central Europe. At the close of the Tertiary Period the climate of the districts above-mentioned seems to have become gradually colder, till at last a cold of Arctic severity prevailed. For, besides the evidence of fossils, we have also proofs of climatic alterations, especially of periods of cold in the markings found on the surface of rocks, and also in the presence of boulder-clay or drift. Rocks striated and polished by glacier action are found in various parts of England and other countries between latitudes 40° and 50°. Boulder-clay is an unstratified deposit containing glaciated stones and blocks, and must have been the mixed morainic material of a great ice-sheet, or it must have been brought by icebergs carrying blocks of stone and mud, which were strewn on the floor as the ice melted. As this boulder-clay is found over several parts of the British Islands, we learn that during this cold period the land was at one time covered with great glaciers and ice-sheets, and at another partly submerged under almost polar waters. Geology, in fact, shows that the northern hemisphere has been subject to considerable oscillations of level, and that periodic recurrences of cold climate have occurred. Signs of similar changes may be found in the southern hemisphere. The 'Great Ice Age' may be regarded as the period which succeeded the deposition of the Pliocene beds at the close of the Tertiary Period ('El. Phys.' par. 264). It probably consisted, in the British Isles, of two glacial epochs separated by a temperate interglacial epoch.

277. **Causes of Changes in Climate.**—The theory that the earth is a slowly cooling globe will account for a gradual lowering of temperature on the surface during the earlier geological periods. But the alternating periods of cold just spoken of require some other cause for their explanation. Several solutions of the problem of these changes have been offered.

I. *Geographical Causes affecting Climate.*—The distribution of land and sea has been shown to have both a considerable direct effect on climate, owing to the different heating effects of the sun on land and water, and a great indirect effect, by deflecting ocean-currents and altering the direction of winds. Any rearrangement of land which shut off the warm waters of the Gulf Stream from the North Sea, would undoubtedly make the climate of Norway much more severe, while a submergence of the British Islands would allow a freer passage for these waters and increase the mean winter temperature of this country. But the special rearrangements of land required to produce the change of climate required, do not appear to have existed at the times in question, nor does it seem probable that these changes alone could have produced the great alterations of temperature indicated. Still, it is quite possible, and even probable, that

important modifications of climate have been produced by geographical causes.

II. *Astronomical Causes affecting Climate.*—We know that the eccentricity of the earth's orbit is variable (par. 179), and that an increase of eccentricity will diminish the perihelion distance of the earth, and increase the aphelion distance. As the earth moves faster when near the sun, the winter of the northern hemisphere is at present eight days shorter than the summer; but when the earth's orbit is at its greatest eccentricity, this difference will amount to thirty-six days. Moreover, the aphelion distance of the earth will then be fourteen millions of miles greater than the perihelion distance. Now the combined effect of precession and the revolution of the line of apsides (par. 179) will be (always assuming the present position of the earth's axis of rotation) to cause the seasons to occur in all parts of the orbit successively, and thus mid-winter would occur at certain periods for each hemisphere when the earth is at perihelion, and then, after a lapse of about 10,500 years, the mid-winter of the same hemisphere would happen at aphelion. Hence at a time of maximum eccentricity the hemisphere with mid-winter at perihelion would have a short and mild winter, and a long, but only moderately hot, summer; while the opposite hemisphere would have a short and hot summer and a long and severe winter. 'The effect of these secular changes would be to place each hemisphere alternately in a state approaching perpetual spring, and under a condition of burning summers and rigorous winters.' Would these astronomical causes produce such great changes of climate as that described as occurring during the glacial epoch? Not directly; for the deficiency of heat during the long winter would be made up during the short hot summer.

278. **Dr. Croll's Theory.**—Though the combination of astronomical causes above described will not account for the full extent of climatic change indicated by the evidence of the rocks, Dr. Croll argues that it would lead to such great alterations in the direction of the permanent winds and ocean currents of the globe, as to account fully for the effects observed. In that hemisphere the winter of which occurred at aphelion when the eccentricity of the earth's orbit was near its highest value, he believes that so great a fall of snow would occur during the long cold winter (what now falls as rain then falling as snow), that the heat of the short summer would fail to melt it all. It would thus accumulate year after year, and these accumulated masses of ice and snow would tend to lower the summer temperature by its reflection of some of the solar rays that fell upon it, and by its absorption of others to perform the work of melting. Snow and ice also lower the temperature by chilling the air and condensing the vapour into thick fogs. These would shut off the sun's rays from the earth's surface, and retard the melting of the snow. 'In short, a state of glaciation is produced on that hemisphere, while exactly opposite effects take place on the other hemisphere, which has its winter in perihelion. The general result is that one hemisphere is cooled and the other heated.' Let us suppose that it is the northern hemisphere that is thus cooled. As a result the north-east trade winds would become stronger than the south-east trade winds, the equatorial calm-belt would be driven south of the equator, and the great equatorial currents would also become moved southwards. The equatorial current of the Atlantic would then impinge on the American coast south of Cape St. Roque, and its warm waters would pass along the Brazilian shore into the Southern Ocean. The Gulf Stream would thus be lost to the North

Atlantic, and the northern hemisphere would lose all the heat derived from that source. Still another cause would lead to the increase of the icy coating of northern lands. The strong under-currents of air forming the north-east trades imply equally strong vapour-laden currents from near the equator. Their moisture would be precipitated as snow on reaching the cold, ice-covered districts of the north. Such in brief is Dr. Croll's explanation of the production of a glacial epoch. Dr. Croll estimates that the last period of great eccentricity began 240,000 years ago, and ended 80,000 years ago, and to this interval he refers the Great Ice Age of the northern hemisphere.

Mr. Wallace, in his work entitled 'Island Life,' thinks that a distribution of land and water tending in the same direction as the astronomical causes would be a still more satisfactory explanation. The importance of the distribution of land and water on the terraqueous globe as a factor in the production of climatic changes has also been emphasised in the most recent volume of 'Challenger Reports.' In the 'Report on Atmospheric Circulation,' Dr. Buchan, after an exhaustive tabulation and discussion of the observations, and after showing by fifty-two newly constructed maps the distribution of the temperature, pressure, and prevailing winds of the globe, summarises the main results thus: 'The isobaric maps show, in the clearest and most conclusive manner, that the distribution of the pressure of the earth's atmosphere is determined by the geographical distribution of land and water in their relations to the varying heat of the sun through the months of the year; and since the relative pressure determines the direction and force of the prevailing winds, and these in their turn the temperature, moisture, rainfall, and in a very great degree the surface currents of the ocean, it is evident that there is here a principle applicable, not merely to the present state of the earth, but also to different distributions of land and water in past times. In truth, it is only by the aid of this principle that any rational attempt, based on causes having a purely terrestrial origin, can be made in explanation of those glacial and warm geological epochs through which the climates of Great Britain and other countries have passed.'

The Zodiacal Light in the Evening Sky. – (*See page* 152.)

APPENDIX

The Greek Alphabet—Capitals and Small Letters.

Letters		Names	Letters		Names
Α	α	Alpha.	Ν	ν	Nu.
Β	β	Bēta.	Ξ	ξ	Xi.
Γ	γ	Gamma.	Ο	ο	Omīcron.
Δ	δ	Delta.	Π	ϖ π	Pi.
Ε	ε	Epsīlon.	Ρ	ρ	Rho.
Ζ	ζ	Zēta.	Σ	σ ς	Sigma.
Η	η	Ēta.	Τ	τ	Tau.
Θ	ϑ θ	Thēta.	Υ	υ	Upsīlon.
Ι	ι	Iōta.	Φ	φ	Phi.
Κ	κ	Kappa.	Χ	χ	Chi.
Λ	λ	Lambda.	Ψ	ψ	Psi.
Μ	μ	Mu.	Ω	ω	Omĕga.

Time Constants

	H.	M.	S.	
The sidereal day	= 23	56	4·090	of mean solar time.
The mean solar day	= 24	2	56·556	of sidereal time.

To reduce a time-interval expressed in units of mean solar time to units of sidereal time, multiply by 1·00273791;

To reduce a time-interval expressed in units of sidereal time to units of mean solar time, multiply by 0·99726957.

	D.	H.	M.	S.
Tropical year (Leverrier, reduced to 1900)	365	5	48	45·51
Sidereal year ,, ,, ,,	365	6	9	8·97
Anomalistic year ,, ,, ,,	365	6	13	48·09
Mean synodical month (new moon to new)	29	12	44	2·684
Sidereal month ,, ,,	27	7	43	11·545
Tropical month (equinox to equinox) . .	27	7	43	4·68
Anomalistic month (perigee to perigee) .	27	13	18	37·44
Nodical month (node to node) . . .	27	5	5	35·81

	°	′	″
Obliquity of the ecliptic (Leverrier)	23	27	08
Constant of precession (Struve)			50·264
Constant of nutation (Peters)			9·223
Constant of aberration (Nyrén)			20·492
Sun's equatorial horizontal parallax			8·8
Moon's *mean* horizontal parallax		57	2·7

TRIGONOMETRICAL FUNCTIONS.

In a triangle the ratios of the sides remain the same as long as the angle remains unchanged, and the magnitude of the angle is determined in Trigonometry by certain ratios called the Trigonometrical Functions.

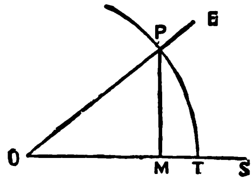

FIG. 175.

Let S O E be an angle less than a right angle, and from the point P in O E let P M be drawn perpendicular to O S. The side O P which is opposite the right angle is called the hypotenuse. Then the ratio of M P to the radius O P is called the *sine* of the angle at O. This ratio is the fraction or number $\frac{\text{perpendicular}}{\text{hypotenuse}}$. If the angle at O be small, the perpendicular becomes small, and the above fraction is small. It will therefore be seen that the value of the sine increases as the angle increases. The ratio of O M to O P is called the *cosine* of the angle at O, and may be expressed by the fraction $\frac{\text{base}}{\text{hypotenuse}}$. The ratio of the side M P to the side O M is called the *tangent* of the angle at O.

$$\text{Thus (1)} \ \frac{MP}{OP} = \frac{\text{perpendicular}}{\text{hypotenuse}} = \sin SOE.$$

$$(2) \ \frac{OM}{OP} = \frac{\text{base}}{\text{hypotenuse}} = \cos SOE.$$

$$(3) \ \frac{MP}{OM} = \frac{\text{perpendicular}}{\text{base}} = \tan SOE.$$

These ratios are mere fractions, and their values vary with the size of the angle. In mathematical tables the value of these ratios for angles of all size may be found. For a very small angle, not exceeding 1° or 2°, the reader will easily see that the perpendicular M P is practically of the same length as the arc T P, and as the fraction *arc*, divided by *radius*, is the circular measure of an angle, the value of the sine and tangent of such an angle are the same as the angle itself when expressed in circular measure (par. 3). Thus an angle of $20''$ is in circular measure $\frac{20}{206,265}$, and this is also the value of the sine and tangent of the angle.

PRINCIPAL ELEMENTS OF THE SOLAR SYSTEM (MAINLY FROM YOUNG'S 'GENERAL ASTRONOMY').

	Name	Symbol	Mean Dist. Millions of Miles	Sidereal Period (mean solar days)	Period in Years	Orbit-Velocity (miles per second).	Eccentricity.	Inclination of Orbit to Ecliptic	Longitude of Ascending Node	Longitude of Perihelion	Longitude at Epoch, Jan. 1, 1850
Terrestrial Planets	Mercury	☿	36·0	87·96926	0·24	23 to 35	·20560	7° 00′ 5″	46° 33′ 9″	75° 7′ 14″	327° 15′ 20″
	Venus	♀	67·2	224·7008	0·62	21·9	·00684	3 23 35	75 19 52	129 27 15	245 33 15
	The Earth	⊕	92·9	365·2564	1·00	18·5	·01677	0 00 00	0 00 0	100 21 22	100 46 44
	Mars	♂	141·5	686·9505	1·88	15·0	·09326	1 51 2	48 23 53	333 17 54	103 25 3
Major Planets	Jupiter	♃	483·3	4332·580	11·86	8·1	·04825	1 18 41	98 56 17	11 54 58	160 1 10
	Saturn	♄	886·0	10759·22	29·46	6·0	·05607	2 29 40	112 20 53	90 6 38	14 52 28
	Uranus	♅	1781·9	30686·82	84·02	4·2	·04634	0 46 20	73 13 54	170 50 7	29 17 51
	Neptune	♆	2791·6	60181·11	164·78	3·4	·00896	1 47 2	130 6 25	45 59 43	334 33 29

	Name	Symbol	Apparent Angular Diameter	Mean Diameter in Miles	Mean Diameter ⊕ = 1	Mass ☉ = 1	Mass ⊕ = 1	Volume ⊕ = 1	Density ⊕ = 1	Density Water = 1	Time of Axial Rotation	Inclination of Equator to Orbit	Oblateness, or Ellipticity
	Sun	☉	32′ 04″ mean	866,400	109·4	1·00000	331100	1,310,000	0·25	1·39	$25^d\ 7^h\ 48^m$	7° 15′	?
	Moon	☾	31′ 26″ „	2,162	0·273	$\frac{1}{26821000}$	$\frac{1}{81}$	0·020	0·61	3·40	27 7 43	6 33±	?
Terrestrial Planets	Mercury	☿	5″ to 13″	3,030	0·382	$\frac{1}{2648700}$?	$\frac{1}{8}$?	0·056	2·23?	12·44?	87·97 days	?	?
	Venus	♀	11″ to 67″	7,500	0·972	$\frac{1}{425000}$	0·78	0·920	0·86	4·85	$23^h\ 21^m\ 23^s$	?	?
	The Earth	⊕	—	7,918	1·000	$\frac{1}{331100}$	1·000	1·000	1·00	5·58	23 56 4·09	23° 27′ 12″	$\frac{1}{293}$
	Mars	♂	3″·6 to 24″·5	4,230	0·534	$\frac{1}{3093500}$	$\frac{1}{9.34}$	0·152	0·72	4·01	24 37 22·72	24 50	$\frac{1}{220}$
Major Planets	Jupiter	♃	32″ to 50″	86,500	10·92	$\frac{1}{1048}$	310·0	1309	0·24	1·33	$9^h\ 55^m$ ±	3° 05′	$\frac{1}{17.0}$
	Saturn	♄	14″ to 20″	71,000	8·97	$\frac{1}{3490}$	94·8	721	0·13	0·72	$10^h\ 14^m\ 24^s$	26 49	$\frac{1}{9}$
	Uranus	♅	3″·8 to 4″·1	31,900	4·03	$\frac{1}{22600}$	14·7	65	0·22	1·22	?	?	$\frac{1}{11}$
	Neptune	♆	2″·7 to 2″·9	34,800	4·39	$\frac{1}{19380}$	17·1	85	0·	1·11	?	?	?

The Meridian Circle.—Fig. 176, from Brinckley's 'Astronomy,' shows a large meridian circle, a transit instrument with two graduated circles attached to the axis, one on each side. These circles are divided from 0° to 360° into spaces of 2′, and are read by micrometer-reading microscopes firmly attached by arms to the two piers on which the instrument rests. The small circle attached to the eye end of the telescope is used as a pointer

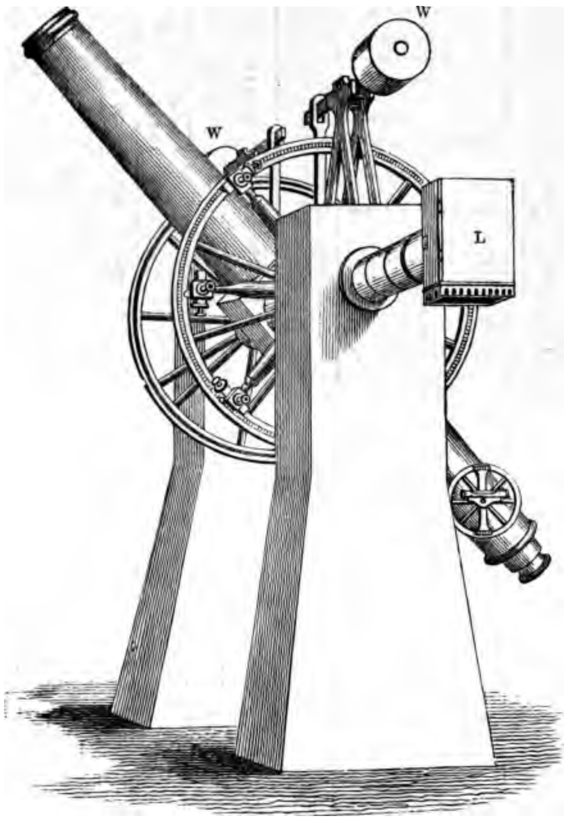

Fig. 176.—Meridian or Transit Circle.

for setting the instrument. On the right is seen the lamp, L, which is used at night to illuminate the reticle. Weights, W W, act on levers supporting the axis, and serve as counterpoises to relieve the pressure with which the axis rests on its supports. The adjustments of the instrument are the same as

those of the transit, and the zenith point of the circle is obtained as explained in par. 47. In some instruments a small circle having a vernier and spirit-level serves as a pointer for setting the instrument at any zenith distance. 'When a transit of a star is being observed, the instrument is firmly clamped by a clamping apparatus attached to the axis, and when the star is near the middle wire the elevation of the telescope is slowly changed by the aid of the micrometer screw, until the star is bisected by the horizontal wire. The reading of the circle gives then, in connection with the zenith point, the zenith distance, and thus also the polar distance of the star, while the mean of the observed times of transits over the wires leads to the knowledge of the right ascension of the star.' If the right ascension of the object is already known, the difference between this and the clock indication will give the *error of the clock*, par. 47.

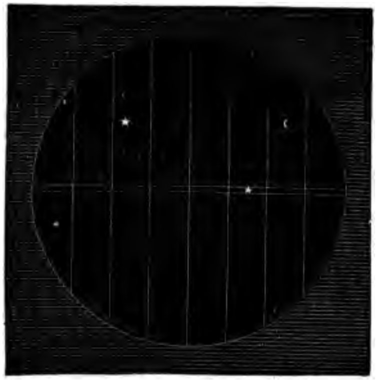

FIG. 177.—The Field of View of a Large Transit Instrument. (Smaller instruments have only five vertical wires, and one horizontal wire.)

Geological Chemistry.—The following article on 'Geological Chemistry,' by F. W. Rudler, F.G.S., is reprinted from the new edition of Watts's 'Dictionary of Chemistry,' most of the references, however, being omitted. 'Since geology is a science which deals primarily with the constitution and history of the earth, it is evident that there must be many points at which it comes into relation, directly or indirectly, with chemistry. Much of geological science is devoted to the study of *rocks*, or those large masses of mineral matter which build up the crust of the earth. The chemist is of service to the geologist not only in analysing these rocks, or the mineral species of which they are composed, but in explaining some of the processes by which the rocks themselves may have been originally formed, and in tracing the nature of the alterations to which they have been subjected since their formation. Hence the geological chemist gives special attention to those natural processes of rock-formation in which chemical reactions are involved, and he endeavours to imitate the operations of nature by experiment in the laboratory. The experimental method was first introduced into geology by Sir James Hall, of Dunglass, who, in order to explain the origin of certain crystalline limestones, subjected pounded chalk to a high temperature in closed gun-barrels, and obtained, under certain conditions, a crystalline mass of carbonate of calcium somewhat resembling a saccharoidal marble. It must be remembered, however, that much of the experimental work recorded in the literature of chemical geology refers to the synthesis of minerals rather than of rocks. A rock may, it is true, be composed of only a single mineral, but in most cases a rock is an aggregate of several distinct mineral species, and although the synthesis of each constituent may be successfully effected, it by no means follows that this work will throw light upon the origin of the composite rock.

Analysis of Rocks.—The simplest method is of course to analyse the rock as a whole, and in the case of a very fine grained rock in which it is impossible to separate the mineral constituents individually, this is the only available method. The interpretation of the results of such an analysis requires, however, considerable sagacity, more especially if the constitution of the rock be complex. Two rocks, distinct in composition, such as a granite and a trachyte, may give the same bulk-analysis, while two rocks of similar mineral composition may yield different analyses. When the oxygen ratio, or quantivalent ratio, of a rock is known, as also that of each of its mineral components, it may be possible to calculate the percentage of each mineral in the rock.

Methods of *fractional analysis* have been introduced for the purpose of effecting a chemical separation of the constituents of certain rocks. Gmelin, in his analyses of phonolites, was perhaps the first to separate the part soluble in hydrochloric acid from that which was insoluble, and to analyse each separately. Grave objections may, however, be urged against this method, and it is now rarely used. More trustworthy results have been obtained by treating the rock, if composed of various silicates, with hydrofluoric acid, which attacks the several minerals in unequal degree. Such a method is sometimes useful in controlling a bulk-analysis.

Of late years considerable use has been made of certain dense liquids for the purpose of effecting the mechanical separation of the minerals which compose a rock, in order that each constituent may be isolated in a state of purity for separate analysis. The S.G. of the liquid is so adjusted that when the rock is coarsely powdered and thrown into the liquid certain of the minerals float while others sink. Several such liquids are now in common use in the geological laboratory (*v.* J. W. Judd, *Proc. Geolog. Assoc.* viii., 278; and F. Rutley, *Rock-forming Minerals*, London, 1888).

Sonstadt's solution, recommended by Church, consists of a solution of HgI_2 and KI; it may be obtained with S.G. 3·196. It is also known as Thoulet's solution. If a rock consisted of plagioclase with S.G. 2·7 and augite with S.G. 3·1, and these minerals were set free by mechanical disintegration of the rock, a complete separation might readily be effected in Sonstadt's solution with S.G. of about 3. The poisonous and corrosive character of the solution, however, tends to limit its use.

The mechanical separation of the constituent minerals of a rock, previous to chemical analysis, is aided by the use of a powerful magnet. With an electro-magnet of great power, silicates rich in iron, such as hornblende, augite, and biotite, may be picked out of the pulverised rock.

Micro-Chemical Examination of Rocks.—The microscopic examination of thin sections of rocks, which forms an important branch of modern petrography, has led to the introduction in recent years of certain microchemical tests for distinguishing one mineral species from another. The micro-chemical methods do not aim at effecting a complete analysis of the microscopic constituents of a rock, but are used rather for the purpose of controlling optical determinations.

The rock may be coarsely powdered in a steel mortar, and the particles to be examined after separation of the fine powder by a sieve may be picked out by aid of the forceps, or if too small may be removed on the point of a needle moistened with glycerine, from which the accumulated grains may be detached by dipping the needle into water. Any steel particles derived from the mortar may be separated by a magnet. In other cases the constituent minerals are so minute that it becomes necessary to

prepare a thin section of the rock and subject it to examination under the microscope. By means of a needle, the grains to be examined may be picked out from the section. It is convenient for the operator to commence by detaching the fragments near the edge, and to work patiently thence towards the centre of the section. The section is, of course, not protected by a cover-glass; and the Canada balsam by which the slice is cemented to the glass is dissolved off by treatment with alcohol.

In some cases the particles to be examined cannot conveniently be separated, and it then becomes necessary to attack the mineral in the section itself. The particular mineral to be tested is brought into the field of the microscope, and a perforated cover-glass is then drawn over the section in such a way that the mineral is just under the perforation. Through this aperture the balsam is dissolved, and the mineral exposed ready for attack by the reagent. If hydrofluoric acid is to be used the section is covered with a perforated slip of platinum foil instead of a cover-glass. By means of a pipette a drop of the solvent is lodged on the slide, and the liquid may then be conducted to the mineral exposed at the aperture by the point of a platinum wire.

The general method in these micro-chemical reactions is to produce certain compounds which present distinctive crystalline forms capable of recognition under the microscope.

The geological chemist is often called upon to decide the nature of a given felspar in a rock, and for this purpose the method introduced by Szabó of Budapest is convenient. An extremely small particle of felspar is introduced into the flame of a Bunsen burner provided with a special chimney of sheet iron. The proportion of soda or potash may be approximately determined by comparing the extent of the yellow or red coloration with the standard plates issued by Szabó. In experienced hands this process yields remarkably precise results.

Classification of Rocks.—Some rocks have evidently been formed as deposits in a watery medium, while others have existed at some period at a high temperature and been more or less completely fused; hence arise two great groups of rock: one of *aqueous*, the other of *igneous*, origin. Certain rocks, whether aqueous or igneous, have suffered such alteration since their formation that their original characters are no longer to be recognised by direct observation, and hence these are known as *metamorphic* rocks. Of the so-called aqueous rocks a few have been deposited directly from solution as chemical precipitates; but by far the larger number have been thrown down as sediments from a state of mechanical suspension. The aqueous deposits are known as *sedimentary* or *stratified* rocks, while the igneous rocks are often described as *unstratified* or *massive*. In addition to these types there are a few rocks, like coal and certain limestones, which owe their origin, directly or indirectly, to organic agencies, and are hence termed *organic* rocks. But though the ultimate origin of such deposits is organic, the changes through which they have passed in reaching their present condition are essentially chemical.

It usually happens that several modes of formation have contributed to the production of a single rock. Thus, rocks formed as chemical precipitates, though practically homogeneous, may contain an admixture of foreign matter representing material that was mechanically thrown down during precipitation. On the other hand, a sedimentary rock frequently has its constituent grains bound together by mineral matter which has been precipitated in association with, or subsequent to, the mechanical deposit, and

has acted as a cementing medium; a sandstone, for example, may have its component grains united by mineral matter precipitated from solutions percolating through the original mass of sand.

In dealing with igneous rocks it is always desirable to ascertain the proportion of silica in the rock as a whole, since a common classification of such rocks is based upon this datum. Bunsen, in studying the rocks of Iceland, suggested that all igneous rocks have been formed by admixture of two magmas which he termed the *normal trachytic* and *normal pyroxenic.* Durocher afterwards developed a theory which derived the rocks from two magmas situated at different subterranean depths, termed by him *acid* and *basic*, and practically corresponding respectively with the trachytic and pyroxenic magmas of Bunsen. At the present time most petrographers define the *acid* or *light* rocks as those containing from 65 to 80 per cent. of silica, and having S.G. 2·3 to 2·7; they usually contain a high proportion of alkalis, especially potash, and but a small percentage of lime, magnesia, and oxides of iron. On the other hand, the *basic* or *dense* rocks contain only from 45 to 55 per cent. of silica, but have S.G. rising from 2·5 to as high as 3·1; they are characterised by a low percentage of alkalis, with more soda than potash, and by a high percentage of lime, magnesia, and oxides of iron (*v.* Teall, *Brit. Pet.*, cap. ii.; and on the classification of igneous rocks, Bonney's anniversary address, *Geol. Soc.*, 41, 1885).

Chemically-formed Rocks.—The chemical precipitates which are of interest to geologists, as having been formed on a large scale by nature, belong chiefly to the groups of carbonates, sulphates, and chlorides, represented respectively by such rocks as limestone, gypsum, and rock-salt. Perhaps the simplest example is offered by *rock-salt*, since this has been formed by the mere evaporation of a natural brine.

Rock-salt has usually been formed in inland sheets of salt-water. These are either isolated portions of the sea, or the relics of lakes which were originally fresh but have acquired salinity by the accumulation of salts introduced by river-waters. The great Salt Lake of Utah, situated in an area of inland drainage, receives streams which bring in salt; but, having no outlet, the waters tend to become concentrated. In this arid region evaporation is rapid, and along the shallow margin of the lake vast quantities of common salt spontaneously crystallise during the dry season; while in winter, whenever the temperature falls below $-6°{\cdot}5$ Na_2SO_4 is precipitated, the quantity of this salt formed in a single season amounting to thousands of tons. Many ancient lakes have in the course of time completely disappeared by desiccation, and their position is now marked by extensive saline deposits.

On the evaporation of a salt-lake, or saline lagoon, the least soluble salts will tend to crystallise first, the order in which the salts are successively deposited being inversely as the order of their solubility. Such a process of fractional crystallisation in nature is illustrated by the remarkable salt-deposits at Stassfurt in Prussia. In the lowest beds the rock-salt is associated with gypsum, anhydrite, and carbonate of calcium; but above the rock-salt there are deposits of deliquescent compounds, rich in potassium and magnesium, which remained in the mother-liquor after the NaCl had separated. The association of the rock-salt and anhydrite in alternate layers has led to the suggestion that they represent seasonal deposits, the former having been deposited in the warmer, and the latter in the colder, parts of the year. The soluble salts above the main mass of rock-salt, known locally

as *Abraumsalze*, consist chiefly of polyhalite ($K_2SO_4, MgSO_4, 2CaSO_4, 2H_2O$), kieserite ($MgSO_4, H_2O$), and carnallite ($KCl, MgCl_2, 6H_2O$).

Origin of Limestone. – One of the commonest examples of a chemically-formed rock is afforded by certain deposits of *limestone* which have ppd. from calcareous waters. Such are the deposits known as *calcareous sinter* or *tufa*, so commonly formed by springs flowing through limestone districts, and forming in some cases important rock-masses, like the *travertine*, or 'Tibur-stone,' of Tuscany. But while certain limestones are the result of direct precipitation, it appears that by far the greater number of such rocks owe their origin to organic agencies. Such, for instance, is the chalk, which is largely made up of the calcareous tests of foraminifera: such, too, are the coral limestones, which are formed in large measure of the hard corallia of certain actinozoa.

When $CaCO_3$ is deposited from thermal springs, the pp. usually takes the form of *aragonite*, the orthorhombic species of $CaCO_3$, harder and denser than calcite. The precipitation of aragonite is well illustrated by the *Sprudelstein* of Carlsbad. The water in which this is formed has a temperature of about 73° C., and though containing only 0·29 per cent. of $CaCO_3$, it readily deposits this salt on cooling. The sprudelstein is commonly oolitic or pisolitic, each little sphere being formed of a series of concentric layers deposited successively around a nucleus, and thus imitating the oolitic structure familiar to geologists in various limestones. The experiments of G. Rose tended to show that when a solution of carbonate of calcium is warm or concentrated it deposits aragonite, while if cold or very dilute it throws down calcite. It has been shown by Credner that the deposition of aragonite is favoured by the presence of gypsum, strontianite, and certain other foreign bodies in the solution from which precipitation proceeds.

Calcareous matter deposited on a large scale is usually more or less impure, and hence limestones become argillaceous, bituminous, &c. On the solution of a limestone by natural solvents, a variable amount of insoluble matter is left, and where the action has extended over long periods the residual impurities, by their accumulation, may acquire considerable importance: such, for instance, is the origin of the deposits on the chalk in this country known as 'clay-with-flints;' and the reddish earth so common in limestone caverns and known as 'cave-earth.'

Origin of Dolomite.—The origin of magnesian limestone, or *dolomite*, has long been a chemical enigma. Since dolomite frequently occurs in association with rock-salt, it has been suggested that it must be of lacustrine origin. Bischof, however, showed long ago the difficulty of simultaneously precipitating $CaCO_3$ and $MgCO_3$ from a solution containing these salts. At the beginning of the evaporation $CaCO_3$ alone falls; towards the close of the process $MgCO_3$ alone: and it is only at intermediate stages that the mixed carbonates are thrown down. It might, therefore, be expected that the geologist would find pure limestone below, succeeded by a deposit of dolomite, and followed above by pure magnesite—a sequence, however, which is not observed in nature. Indeed, dolomite seems to have been formed not so much by direct ppn. on the evaporation of waters in which the two carbonates co-existed as by certain chemical reactions.

Sterry Hunt has pointed out that the interaction between carbonate of sodium and the chlorides of magnesium and calcium in sea-water would give rise to dolomite, with simultaneous production of chloride of sodium, thus explaining the common association of dolomite with rock-salt. There

seems no difficulty in providing the necessary quantity of Na_2CO_3, inasmuch as various soda-bearing silicates, notably the soda-felspars, are commonly suffering decomposition in nature by the action of carbonated waters, with consequent formation of Na_2CO_3 and separation of silica. Another reaction suggested by Sterry Hunt is that which may occur between $CaCO_3$ and $MgSO_4$; the resulting $MgCO_3$ may, under certain conditions, become associated with fresh $CaCO_3$, so as to form dolomite, which will then be accompanied by a precipitate of $CaSO_4$. As a matter of fact, nothing is more common than to find dolomite naturally associated with gypsum (*Chem. and Geol. Essays*, 1875, 90).

Hoppe-Seyler obtained dolomite by heating carbonate of calcium in a solution of bicarbonate of magnesium in a sealed tube at 100° C. Possibly in some cases dolomite has been formed under abnormal conditions of temperature. The crystalline dolomites, enormously developed in the Triassic series of the Eastern Alps, are believed to be metamorphic rocks, or ordinary limestones which have become dolomitised (*v. infra*).

Weathering of Rocks.—Most rocks on or near the surface of the earth have suffered more or less chemical change by the natural action of air and water. This weathering usually takes the form of *oxidation* and *hydration*; thus, rocks such as basalt, which contain minerals rich in iron, exhibit along their joint-planes a rusty appearance, due to the formation of ferric hydrate. Deposits of brown iron-ore of great magnitude may result from the alteration of masses of iron-pyrites. Such, too, is the origin of the *gossan*, or impure brown iron-ore commonly found in the upper part of mineral veins where anogenic action has been rife, and known to Continental miners as the *Chapeau de fer* or *Eiserne Hut*. Many clays and other rocks present in their unaltered condition a bluish or grey colour, due to the presence of finely disseminated iron pyrites, which in like manner decomposes on exposure, yielding ferrous sulphate, and finally ferric hydrate, and the rock thus assuming brown and yellow tints.

On the other hand, a process of *deoxidation* may frequently be traced in the natural alteration of rocks and minerals, the principal reducing agent being organic matter. Sulphates may thus be reduced to sulphides; whence, in many cases, the origin of iron-pyrites—a mineral commonly found in association with coal, fossil wood, shells, and other organic remains. In like manner gypsum may be reduced to the condition of sulphide of calcium, and this, if dissolved in water containing carbonic acid, will yield carbonate of calcium and sulphuretted hydrogen, the latter readily depositing free sulphur on exposure to the air. Hence probably the origin of the associated deposits of gypsum, sulphur, and limestone, so familiar to the geologist in Sicily and other sulphur-bearing localities. The removal of crystals of selenite from clays and other rocks may be due to similar reactions and not to mere solution.

It has long been known that the organic acid resulting from the decomposition of vegetable matter may exert a bleaching action upon red and brown rocks, by reducing the ferric oxide to a lower state of oxidation. It has been suggested that some of the finest white glass-making sands may have been derived from sands originally yellow or brown, but decolorised in this way. At the same time such reducing action appears incompetent to explain the local decoloration observed in many variegated rocks.

Hydration, though usually accompanying oxidation, may occur in nature without any other chemical change. A common illustration of such action is seen in the conversion of anhydrite into gypsum by absorption of two

molecules of water. This change is accompanied by a marked increase in bulk, 1 vol. of $CaSO_4$ becoming 1·6 vol. of $CaSO_4, 2H_2O$. The galleries of deserted mines in which anhydrite has been worked have become closed by the swelling of the walls, consequent on hydration of the mineral. Geologists believe that a similar increment of bulk, occurring on a large scale in deep-seated deposits, may account for certain minor movements of the earth's crust.

Origin of Kaolin.—It is commonly said that one of the most striking examples of weathering is afforded by the decomposition of the felspar in granitic and other rocks. Meteoric waters, containing carbonic and organic acids, readily attack felspathic minerals, removing the alkalis in a soluble form, while the silicate of aluminium, in a hydrated condition, remains behind as clay. *Kaolin*, or china-clay, the purest form of argillaceous matter, may thus be derived from felspar-bearing rocks, especially granites. It was seriously held that the great heat experienced in working the Comstock lode was due to the kaolinisation of the felspars in the surrounding rocks—a suggestion, however, entirely disproved by experiment. In Cornwall it is not uncommon to find granite in which the orthoclase, or potash-felspar, is more or less decomposed, while the associated silicates remain almost unaltered: such a rock is known as *china-stone* or *petunzite*; while a rock in which the felspar is entirely kaolinised is termed *china-clay rock* or *carclazite*. It is frequently held that the simple action of meteoric waters, charged with carbonic and organic acids, is sufficient to explain the origin of kaolin; but though kaolinisation may undoubtedly result from mere weathering, it seems that superficial action is incompetent to explain all the observed phenomena. The change appears rather to have been effected by means of solutions derived from deep-seated sources, circulating in the joints of the granite. It has often been pointed out that the decomposed granite is associated with minerals containing fluorine (like lepidolite) or fluorine and boron (like schorl). Von Buch in 1824, and Daubrée in 1841, suggested that the change has been due to hydrofluoric acid or other fluorides, which, acting upon the granite at an elevated temperature, would decompose the felspar, removing its alkali as a fluoride. Cassiterite (SnO_2) is a common associate of the kaolinised granite, and there is reason to believe that this mineral has been produced by the agency of fluorine.

Metamorphism.—A rock, whether of aqueous or of igneous origin, is said to be *metamorphic* when it has been altered not by atmospheric agencies, but by some profounder influence which has so affected its structure and composition that its original character is no longer to be recognised by direct observation. Thus the intrusion of an igneous rock among sedimentary strata may give rise to changes known as *contact metamorphism*. By such action an ordinary limestone may be converted into a crystalline marble—a phase of metamorphism conveniently distinguished by A. Geikie as *marmorosis*. The production of a saccharoidal marble from an amorphous limestone under the influence of heat and pressure was illustrated by James Hall's experiments in the early part of this century.

The effects of contact metamorphism are partly physical and partly chemical. To the former class may be referred not only the crystallisation of limestone but the induration and even fusion of various other rocks, and the development of prismatic structure in the neighbourhood of the heated mass. Among ordinary chemical effects may be noted the expulsion of water, the reddening of a calcined rock, and the conversion of coal into a natural coke. But the most interesting phenomena are those attending the

development of new minerals. Thus, a slate in the neighbourhood of an intrusive granite frequently contains garnets, chiastolite, and other crystallised silicates; while metamorphic limestones may enclose rock-crystal, garnets, idocrase, micas, and other minerals which appear to have been produced by the rearrangement and crystallisation of the materials of the sand, clay, and other impurities originally present in the limestone. The ejected limestone blocks of Monte Somma, consisting originally of the sub-Apennine limestone, are rich in minerals of this character, and have lately been specially studied by J. H. Johnston-Lavis, of Naples.

When metamorphic rocks extend over a wide area and are not visibly associated with igneous rocks to which their alteration may be referred, they are said to be due to *regional metamorphism*. The agencies by which such phenomena have been produced are exceedingly obscure, but while many of the changes are of a chemical and molecular character, it is evident that molar forces have been operating on a large scale. Of late years it has been recognised that the mechanical movements of the rocks have largely contributed to the production of the characteristic structures in those metamorphic rocks known as the crystalline schists, not only producing deformation of the constituent minerals, but indirectly causing the passage of one mineral into another.

Hydrothermal Action.—The effects of thermal metamorphic agencies, even in the neighbourhood of an igneous rock, are usually due, not so much to dry heat as to hydrothermal action. Although pure water at ordinary temperature and pressure is capable of slowly dissolving the common mineral-constituents of rocks, its solvent action is vastly increased by the great heat and pressure to which it must be subjected in the deeper-seated portions of the earth's crust, where metamorphism probably has its normal seat. Such action is well illustrated by the remarkable experiments of Daubrée. This observer found that when water was heated in strong glass tubes enclosed in thick wrought-iron cylinders, and exposed uninterruptedly to a temperature of at least 400° C. for several weeks, the glass was transformed into a hydrated silicate, analogous to a natural zeolite, while the interior of the tube became lined with a crust of small transparent crystals of quartz. In some cases the artificial crystals of quartz lined the walls of the tube like the quartz in a natural geode (*ib.* 166).

The solvent action of water at great depths accounts for the peculiar composition of the water of geysers. Under enormous pressure, and at a high temperature, these waters are capable of decomposing the volcanic rocks which they traverse, and of dissolving out silica. Thus, water from the Opal Spring in the Yellowstone National Park contained as much as 53·76 g. of silica to the imperial gallon. On the evaporation of such water the silica is deposited in a hydrated form as a kind of opal or siliceous sinter, known as *fiorite* or *geyserite*.

Dolomitisation.—Among cases of metamorphism, that of the alteration of a normal limestone into dolomite has long been recognised and variously explained. Von Buch and certain other German geologists, looking at the association of crystalline dolomite with basic igneous rocks in the Tyrol, held that these erupted masses had emitted vapours containing compounds of magnesium which had acted upon the neighbouring limestone, causing dolomitisation. In support of such a view it was pointed out by Durocher that when fragments of limestone are heated with $MgCl_2$ in a closed vessel, the limestone is partially converted into dolomite. Such an action, however, if it occurs at all in nature, must be limited to the immediate neigh-

bourhood of the heated body evolving the magnesian vapours. In order to explain the alteration of large masses of limestone, it is simpler to invoke the agency of percolating water holding compounds of magnesium in solution. Even where limestone has been dolomitised in contact with basalt, Bischof contended that the change was due to the action of water containing $MgCO_3$ resulting from the decomposition of the magnesian silicates in the igneous rock.

When water containing carbonate of magnesium percolates through a limestone, the magnesium salt tends to unite with part of the calcium carbonate so as to form a double salt, while $CaCO_3$ is at the same time dissolved out. For every molecule of $CaCO_3$ removed, a molecule of $MgCO_3$ is introduced, the change being accompanied by a diminution of volume to the extent of 12 or 13 p.c. Now it is a remarkable fact that natural dolomites are frequently marked by a cellular or cavernous texture, and Elie de Beaumont long ago suggested that the cavities were due to shrinkage consequent on dolomitisation. It is estimated that in many magnesian limestones the hollows represent about 12 p.c. of the bulk of the rock. The sulphate and chloride of magnesium in sea-water may also transform limestone into dolomite, but according to Favre the action requires a temperature of 200° C., favoured by great pressure.

$MgCO_3$ is not the only carbonate which has been introduced into certain limestones by secondary processes. In some cases beds of limestone have been more or less completely transformed into $FeCO_3$—a change well illustrated on a large scale in the important deposits of Cleveland ironstone in the Middle Lias of N.E. Yorkshire. Sorby believes that this ore has been formed from an oolitic limestone by percolation of water containing bicarbonate of iron in solution. Most of the fossil shells associated with the ore have suffered a like conversion, and in some cases the ferrous carbonate has been further changed into ferric hydrate.

Serpentinisation.—The origin of serpentine has been a subject of much discussion, in which the geologist has had to appeal to the chemist. By most modern petrographers it is regarded as an altered eruptive rock, having been derived mainly from olivine. Pseudomorphs of serpentine after olivine are familiar to the mineralogist, and an action similar to that which produced this alteration appears to have been concerned in the metamorphism of large rock-masses. This view has gained much credence of late years by the study of the microscopic structure of serpentine by Sandberger, Tschermak, Bonney, and other petrographers. Hydration is effected by water gaining access to the olivine through the irregular fissures by which the mineral is usually traversed; and in the case of ferriferous olivines the iron is deposited in the form of magnetite and limonite (*v.* Teall, *Brit. Petrog.*, 1888, p. 104).

While many serpentines suggest by their occurrence as dykes and bosses that they have been derived from eruptive rocks, others occur in beds intercalated among crystalline schists, especially in association with limestone. It has been supposed that such serpentine may have resulted from the alteration of dolomite or some other magnesian rock of aqueous origin. Sterry Hunt, who is especially familiar with the serpentines of the Laurentian series of Canada, has always argued against the derivation of serpentine from igneous rocks, and regards it simply as a product of direct precipitation from natural waters. He holds that by the decomposition of the various crystalline silicates in nature, soluble silicates of the alkalis and of lime are set free, and passing into streams are ultimately mixed with waters

rich in magnesium salts—such as the sulphate or chloride in sea-water—when double decomposition ensues, and silicate of magnesium is precipitated in a gelatinous condition.

Recent Formation of Minerals.—Observations on the production of minerals under known conditions in historic times are of much interest to the geological chemist, inasmuch as they suggest the processes which may have operated in nature during geological time. Daubrée long ago called attention to the production of a series of minerals since the Roman period at the hot springs of Plombières in the Vosges. Around these springs the Romans had built walls of concrete, consisting of brick and stone cemented by mortar. By the action of the waters at 50° C. upon the concrete, there has been formed a series of minerals including chabazite, harmatome, mesotype, and other zeolites, associated with opal, calcite, &c. Similar effects have been observed at other Roman baths.

Geodes.—The production of certain minerals at the Roman stations just cited, recalls the natural formation of similar substances in the cavities of basaltic and other rocks. These cavities, though perhaps in some cases due to the removal of pre-existing crystals by solution, usually represent bubbles produced by the disengagement of gas or steam at a time when the igneous rock was in a plastic condition. The minerals occurring in such cavities are of secondary origin, having been introduced through the medium of solutions permeating the rock long after solidification. When the vesicles are filled with mineral matter, the rock is said to be *amygdaloidal*; if the cavities are not completely filled, and the walls are lined with crystals, they are termed *geodes*. The most common of these secondary minerals are calcite and silica, the latter frequently forming agates. In an agate, regular layers of colloidal, crypto-crystalline, and crystalline silica succeed each other with regularity (*Mineral Mag.* v. 34).

Origin of Mineral Veins.—The deposition of secondary minerals in the cavities of rocks, tends to throw light upon the formation of mineral veins, or lodes—a subject on which the geologist has frequently appealed to the chemist. It is now generally held that these veins represent fissures filled in by deposition of mineral matter from a state of solution. The chief difficulty is to trace the metalliferous minerals to their origin. The most promising modern researches are those of Professor Fridolin Sandberger, of Würzburg. By comparative analyses of the ore, the veinstone, and the country rock, he has shown that the contents of the lode have been derived in certain cases from the neighbouring rocks, and that the ores have probably obtained their metallic elements from the common constituents of the crystalline rocks, which had not previously been suspected to contain such metals. Analyses of ordinary rock-forming minerals, like mica, augite, hornblende, and olivine, revealed the presence in them of a large number of the heavy metals. Nor is it only in the crystalline rocks that such metals occur, Dieulafait having shown that many of them are widely distributed in minute proportion through the stratified rocks. Such an occurrence is readily explicable by the fact that most sedimentary strata have been derived, directly or indirectly, from the disintegration of the older crystalline rocks.

Some interesting phenomena tending to illustrate the origin of certain mineral veins have been studied in districts in California and Nevada, where hydrothermal action is rife. Hot water, steam, carbonic acid, sulphuretted hydrogen, and other gases escape from fissures in volcanic rocks, and on the walls of these fissures they deposit siliceous sinter associated

with free sulphur, cinnabar, iron-pyrites, and other metalliferous minerals, including metallic gold—the whole assemblage being suggestive of the contents of certain veins.

Durocher and some other observers have argued in favour of many metallic minerals in lodes having been produced by sublimation. In Durocher's experiments he succeeded in producing galena, iron-pyrites, zinc-blende, and other metallic sulphides, by passing certain vapours through glass tubes at a high temperature.

Chemistry of the Volcano.—The chemical operations involved in volcanic phenomena are extremely obscure. It is generally admitted that water is the prime factor in the production of these phenomena, and as the temperature prevailing at volcanic foci probably exceeds the critical point of water it must exist in the form of vapour, notwithstanding the enormous pressure to which it is subjected: possibly the temperature is so high that the water is dissociated. Fouqué found in the lava of Santorin of 1876 a notable quantity of free hydrogen co-existing with free oxygen. The volcanic vapours associated with steam are chiefly HCl, SO_2, CO_2, H_2S, free O, H, and N, and sometimes NH_3 and CH_4. The HCl may be due to access of sea-water, most volcanoes being situated on islands, or, if on the mainland, near to the sea-coast. Ricciardi has found that finely powdered granite and lava mixed with pure NaCl evolve HCl when heated, the quantity being increased by blowing in a current of steam. The sublimed products of volcanic rocks include a large number of metallic chlorides, notably those of NH_4, Na, Fe, Cu, Ca, and Mg.

The SO_2 of volcanic exhalations has been referred by Ricciardi to the reaction of silica with $CaSO_4$ and $MgSO_4$, whereby silicates are produced, with separation of sulphur trioxide, which is resolved into sulphur dioxide and oxygen. He found that granite mixed with the sulphates cited above would evolve SO_2 when heated. By the interaction of SO_2 and H_2S free sulphur is produced and deposited as an incrustation on the lava. By oxidation, sulphuric acid is developed, and this by its action on the volcanic rocks tends to decompose them, with production of various sulphates. Thus it comes about that alum is manufactured in the crater of Vulcano, one of the Lipari Islands, and at the Solfatara, near Naples. The term 'solfatara' is now used by geologists as a general designation for a volcano which is approaching extinction and emits only vapours. Long after other emanations cease, CO_2 may be exhaled, as in many localities in the Eifel and in Auvergne. Boric acid, in a finely-divided condition, is produced from the nearly-exhausted crater of Vulcano, and from the *mofette* of Tuscany, where it has long been utilised industrially. (On the general subject of volcanoes, *v.* Judd's volume in the International Science Series.)

Synthesis of Igneous Rocks.—The artificial reproduction of many igneous rocks has been successfully accomplished in recent years by Fouqué and Lévy in the geological laboratory of the Collège de France, in Paris. These observers have shown that a number of basic eruptive rocks can be formed by the fusion of their constituents, and that the products, examined in thin sections under the microscope, are identical in structure and composition with the corresponding natural rocks. It had previously been supposed that water, in some form, played a conspicuous part in the liquefaction of igneous rocks, and that this was in fact due not to dry fusion but rather to hydrothermal action. The syntheses performed by Fouqué and Lévy controverted this view, inasmuch as they were effected solely

by dry igneous fusion, without the presence of water or any other volatile medium, and without flux or other chemical agent.

The raw materials employed by these experimentalists were either the component minerals of the rocks to be produced (such as feispar, augite, &c.), or the chemical constituents of these minerals (silica, alumina, lime, &c.). These minerals, corresponding in their relative proportions with the composition of the rock to be imitated, were introduced, in a pulverised condition, into a platinum crucible of about 20 c.c. capacity, furnished with a cover. The crucible was heated in a furnace of Forquignon and Leclerc's type, heated by a Schlösing blowpipe, whereby it could be rapidly raised to a white heat, or reduced at will to a lower temperature, and the heat maintained constant for a long period. The first fusion at a white heat always yielded an isotropic glass, and this, if cooled suddenly, maintained its vitreous character. But if the fused product was kept for some time at a temperature below white heat, yet above that of the melting-point of the glass, various crystalline products were developed; and by subjecting the material to successively diminishing temperatures, other products crystallised out, the least fusible being the first to separate.

By a process of fractional crystallisation conducted in this way, Fouqué and Lévy imitated the conditions which appear to have obtained during the formation of volcanic rocks, where the crystallised constituents represent successive periods of consolidation. Artificial basalt was obtained by fusing a mixture of the elements of olivine, augite, and labradorite, and subjecting the resulting black glass to a bright red heat for 48 hours, when the olivine, which is the least fusible component, was found to be crystallised. Then on submitting the mass to a cherry-red heat for another 48 hours, the microlitic crystals of the more fusible minerals separated: these were the lath-shaped crystals of plagioclase and augite, which may be regarded as minerals of the second period of consolidation. Some of the most remarkable experiments were those on the so-called ophites. These are doleritic rocks, in which the augite forms comparatively large plates moulded around the crystals of plagioclase; the former having evidently been of subsequent consolidation to the latter. By a succession of suitable coolings and re-heatings this ophitic structure was perfectly imitated.

Notwithstanding the remarkable success with which the basic igneous rocks have lately been imitated, all experiments on the synthetical formation of the acid rocks have hitherto been fruitless. The reproduction of these natural products forms one of the most interesting fields of investigation left open to the geological chemist.

Note to par. 176, page 201.

Geological Action of Tides.—*Age of the Earth.*—According to Professor Darwin's theory of tidal evolution, the moon must have been much nearer the earth in the earliest geological periods, and its tide-producing power must, therefore, have been much greater. Hence it must have played a much more important part at this period in the production and transport of the sediment which is laid down in beds and consolidated into rock than it does now. 'As the waves batter against the coast they gradually wear away and crumble down the mightiest cliffs, and waft the sand and mud thus produced to augment that which has been brought down by the rivers. In this operation also the tides play a part of conspicuous importance, and where the ebb and flow is greatest it is obvious

that an additional impetus will be given to the manufacture of stratified rocks. In fact, we may regard the waters of the globe as a mighty mill, incessantly occupied in grinding up materials for future strata. The main operating power of this mill is of course derived from the sun, for it is the sun which brings up the rains to nourish the rivers, it is the sun which raises the wind which lashes the waves against the shore. But there is an auxiliary power to keep the mill in motion, and that auxiliary power is afforded by the tides. If then we find that by any cause the efficiency of the tides is increased, we shall find that the mill for the manufacture of strata obtains a corresponding accession to its capacity. Assuming the estimate of Professor Darwin, that the tide may have had twice as great a vertical range of ebb and flow within geological times as it has at present, we find a considerable addition to the efficiency of the ocean in the manufacture of the ancient stratified rocks. . . . The velocity of all tidal currents would also be greater than at present, and as the power of a current of water for transporting solid material held in suspension increases rapidly with the velocity, so we may infer that the efficiency of tidal currents as a vehicle for the transport of comminuted rocks would be greatly increased. It is thus obvious that tides with a rise and fall double in vertical height of those which we know at present would add a large increase to their efficiency as geological agents. Indeed, even were the tides only half or one-third greater than those we know now, we might reasonably expect that the manufacture of stratified rocks must have proceeded more rapidly than at present.'[1] These primeval tides may, therefore, furnish a possible partial solution of the difficulty of geological time referred to in par. 95, for the enormous thickness of the Laurentian, Cambrian, and other Palæozoic strata may have been produced at a rapid rate as the result of these gigantic tides. But the difficult problem of the age of the world is not entirely solved by these primitive tides. Some of the more recent formations ('El. Phys.' par. 264) must have been produced very slowly. The chalk formation, for example, is in England 3,500 feet thick. Suppose it was formed at the same rate as the modern deposit in the bed of the Atlantic, $\frac{1}{5}$ inch per annum. The time required would be $3{,}500 \times 12 \times 5 = 21{,}000$ years. To this must be added the vast time needed to produce and bring into their present conditions all the other beds above and below the chalk. The problem is thus stated by Mr. Sydney Lupton in *Nature*, Feb. 14, 1889: 'Arguments based upon (1) the internal heat of the earth; (2) the retardation of the rotation of the earth due to tidal friction; (3) the temperature of the sun, seem to show that the earth has not continued under present conditions for more than from ten to a hundred millions of years; while the theory of evolution probably requires at least three hundred millions of years for even a comparatively brief portion of geological history. The two results, each supported by strong evidence, are at present in contradiction to each other.'

Note to par. 188.

For a long time it was debated whether the earth was an oblate spheroid flattened at the poles or a prolate spheroid flattened at the equator. The erroneous view was held by the followers of Cassini, an Italian astronomer (1625 to 1712), but the measurement of the Lapland arc by Maupertuis in 1738 definitely settled the question, and 'flattened

[1] *Time and Tide*, by Sir Robert S. Ball, LL.D.

the poles and the Cassinis.' Other geodetic measurements in connection with the latitudes and longitudes of the places of observation have enabled us to determine both the dimensions and true shape of the earth. The *form* of the earth, though not its *size*, may also be determined by observations of the force of gravity at various points on its surface. Experiments clearly show that the force of gravity is greater by about $\frac{1}{190}$th part at the pole than at the equator. Hence a body weighing in a spring-balance ('El. Phys.' par. 18) 190 pounds at the equator would weigh 191 pounds at the pole; or, to put it in another way, a pound of lead at the equator would have a greater mass, i.e. contain more matter, than at the poles. The intensity of gravity at the earth's surface is measured by the acceleration produced in a body falling freely under its influence. It is best found by pendulum experiments, and is often denoted by g. The value of g expressed in feet per second is 32 ft. 3 in. at the pole and 32 ft. 1 in. at the equator. At London, lat. $51\frac{1}{2}°$, the acceleration produced by gravity is 32 ft. 2 in. nearly.

A portion of the diminished force of gravity is a result of the earth's axial rotation. This centrifugal tendency, which is not a real force, but only a consequence of *inertia*, leads anything which is revolving round a centre to get farther from the centre and to pass off at a tangent when the constraining or centripetal force is withdrawn. Now bodies at the earth's surface are whirling round at the equator with a velocity of more than 1,000 miles an hour, but this velocity gradually diminishes up to zero at the poles. Calculation shows that the force of gravity at the equator is diminished $\frac{1}{289}$th part by this centrifugal tendency alone, and that if the earth turned round 17 times faster centrifugal tendency would so far increase that it would just balance the force of gravity at the equator. The remainder of the difference in the force of gravity at the equator and the poles can only be accounted for by supposing that at the pole a body is nearer to the centre of the earth than it is at the equator. In other words, the difference, $\frac{1}{193}$, between equatorial and polar gravity is made up of a difference of $\frac{1}{289}$ due to the 'centrifugal force' of the earth's rotation and a difference of $\frac{1}{590}$ due to the ellipsoidal shape of the earth.

A degree of *latitude* as measured along an arc of a meridian in the way already described (par. 187) increases slightly as we pass from the equator towards the poles owing to the earth being thus an oblate spheroid in shape. From the arcs that have been measured in Peru, India, England, Russia, Sweden, South Africa, and other countries, the following figures have been obtained:—

At the equator one	degree	of	latitude	=68·704 miles
At lat. 20°	,,	,,	,,	=68·787 ,,
,, 40°	,,	,,	,,	=68·993 ,,
,, 60°	,,	,,	,,	=69·229 ,,
,, 80°	,,	,,	,,	=69·386 ,,
At the pole	,,	,,	,,	=69·407 ,,

A degree of *longitude* is the length between two meridians that make an angle of one degree at the poles measured on a circle parallel to the equator. As such circles (parallels of latitude) are greatest at the equator and decrease to zero at the poles, it is clear that the length of a degree of *longitude* diminishes rapidly as we approach either pole. At the equator a degree of longitude = 69·16 miles; at lat. 20° it = 64·63 miles; at

lat. 40° it = 53·05 miles; at lat. 60° it = 34·66 miles; at lat. 80° it = 12·04 miles; and at the poles it is zero.

Note to par. 222.

Prof. Vogel has divided stellar spectra into three classes:—Class I. Metallic lines feeble. Class II. Metallic lines prominent. Class III. Banded spectra. Each of these classes is then subdivided. The relation between Vogel's system of classification and the systems of Secchi and Lockyer may be set forth as follows:—

SECCHI		VOGEL		LOCKYER
Type I.	=	Class I. *a*	=	Group IV.
Type II.	=	Class II. *a*	=	Groups III. and V.
Type III.	=	Class III. *a*	=	Group II.
Type IV.	=	Class III. *b*	=	Group VI.
Type V.	=	Classes I. *c* and II. *b*	=	Group I.

It is worthy of note that the three elements most commonly found in stars, as indicated by their spectra, are hydrogen, sodium, and magnesium. Iron is also frequently detected, as in Sirius (fig. 150), Vega, and Pollux, whilst others, as Arcturus, show calcium and chromium in addition.

Note to par. 245.

The theory of the formation of hail has been set forth by Ferrel. Hail storms are simply tornadoes in which the ascending gyratory air-currents are so strong that the rain-drops formed below are carried upwards into regions so cold that they become frozen into ice. Thrown outside the gyrations of the tornado above, they then fall as solid hail-stones. In some cases the origin of the hail-stone is a snow-flake formed in the snow region and carried up by the tornado until it freezes. Receiving a coating of rain as it ascends and falls, it reaches the earth as a hail-stone with a kernel of frozen snow at its centre. In some cases the descending hail is drawn in towards the vortex of the tornado and is again carried up and receives a coating of frozen snow or ice. This process may be repeated several times, so that at last there falls to the earth a hail-stone with a number of alternate coatings of ice and snow. By the process of regelation a number of impinging hail-stones are often frozen together as they pass through the air. Such masses sometimes fall as large as a man's fist, and their fall is very destructive.

SYLLABUS OF THE SCIENCE AND ART DEPARTMENT, SOUTH KENSINGTON.

SUBJECT XXIII.—PHYSIOGRAPHY.

Second, or Advanced Stage.

Questions may be set in all the topics included in the elementary course, and, in addition, in the following ones:—

General Survey of the Solar System.—Major planets; minor planets. Inclination of the equatorial planes of the chief planets to the ecliptic; nodes. Satellites. Inclination of orbits. Comets and meteors; peculiarities of their orbits.

Dimensions of the Solar System.—Measurement of the surface, size, and true shape of the earth. General idea of the work of geodetical surveys, and the instruments employed. Measurement of the distances of the moon and sun. Sizes of planets and satellites. Diameters of orbits of satellites.

Gravitational Energy.—Interaction of mass on mass (gravitation). Measurement of the earth's density; methods employed and results obtained. Effects of the gravitational energy of celestial bodies on the earth. The form of the earth's orbit, and its varying speed during revolution round the sun. Combined effect of the sun and moon on the ocean; the tides and their effects. Precession; nutation; changes in the line of apsides.

Study of the Radiant Energy of Celestial Bodies.—Classification into hot and cold masses; bodies studied by their radiation alone; by their radiation and absorption; by their reflection; general idea of the distribution of these masses, and of the dimensions of the sidereal system. Stars; classification according to their spectra; variable stars; coloured stars. Nebulæ. Comets and meteorites.

Physical and Chemical Constitution of the Sun.—Solar spectrum; Fraunhofer lines; physical features; size and mass. Distribution of sun-spots and prominences; spot and prominence periods.

Terrestrial Effects of the Sun's Radiant Energy.—Effects on the atmosphere; changes in barometric pressure; how air-currents are produced; trades; cyclones and anti-cyclones; monsoons; changes of direction of air-currents. Effects on the ocean; the chief streams and currents. Effects on the vegetable kingdom. Explanation of the daily and yearly changes

in the meteorology of the earth. Possible eleven-yearly changes. The various causes of secular changes of climate and their effects. Changes in the distribution of terrestrial magnetism and electricity. Instruments and methods employed. Secular changes in the magnetism of the earth.

The other Planets and Satellites of the Solar System compared with the Earth and Moon.—Masses; densities; rotation-periods; atmospheres; temperatures; surface-markings.

The Earth as a cooling Globe.—The secular cooling of the earth. The earth's interior. Conditions of a cooling and contracting globe. The present conditions of non-terrestrial matter as throwing light on the past history of the earth. Comparisons of solar and terrestrial chemistry. Kant's hypothesis.

HONOURS.

The candidate must possess a sound knowledge of all the subjects contained in the syllabus, but he will be expected in addition to show a thorough acquaintance with one of the main groups, including the advances which have recently been made in it.

QUESTIONS FOR REVIEW.

Those marked with a star are taken from papers set by the Science and Art Department.

1.* Describe how the position of a star is defined.

2.* How are the daily and yearly apparent motions of the stars explained?

3. Define the terms:—meridian, right ascension, declination, prime vertical, zodiac, solstices, obliquity of ecliptic.

4. Where is the constellation Aries now in relation to the intersection of the ecliptic and equator, and why is it removed?

5.* Describe the construction of both a reflecting and a refracting telescope.

6.* Describe the construction of an achromatic object-glass.

7. Why does atmospheric refraction increase a star's altitude? Where is it greatest and where least?

8.* State what you know about Kepler's laws.

9.* What is the synodic period of a planet?

10.* What are the chief elements of a planet's orbit?

11.* What are the views entertained at present concerning the nature of Saturn's rings, and what are the facts on which these views are based?

12.* What is the cause of the seasons? Contrast the seasons of Mars and Jupiter.

13.* How are observations made with the transit-circle, and what is their object?

14.* Describe the uses of the transit instrument.

15.* Draw the apparent form of the moon at the first and third

quarters, and give diagrams showing the relative positions of the moon, earth, and sun, at these periods of the lunar month.

16. What conditions must concur to produce a lunar eclipse? Why can there not be an annular eclipse of the moon?

17. Why is the sidereal month shorter than the synodic? How many times does the moon turn on its axis in a year?

18.* State what you know about the composition of white light, and show (1) how this may be studied by simple experiments, and (2) its bearing upon the composition of stars?

19.* Explain the terms 'dispersion' and 'minimum deviation' as applied to a ray of light.

20.* Describe the construction and mode of use of the spectroscope. State what you know about the spectrum of sodium, of chlorine, and of the sun.

21.* How do we account for the dark lines in the solar spectrum?

22.* What has the spectroscope taught us respecting the chemical and physical constitution of the atmosphere of the sun?

23.* State what you know about sun-spots, and explain the terms, corona, chromosphere, photosphere, faculæ.

24.* Describe the surface of the planet Mars.

25. When is a planet an evening star? When a morning star?

26. Can there be a transit of Mars across the sun's disc?

27. How is the rotation of the sun on its axis proved?

28. What is the motion of the moon's nodes?

29. Describe some of the telescopic features of the moon.

30. How can the distance of a meteor from the observer, and its height above the earth, be determined?

31.* What are the principal phenomena observed in a total eclipse of the sun?

32.* What terrestrial phenomena seem to be connected with the number of spots seen on the sun at different times?

33.* How are the tides caused, and what is meant by 'spring' and 'neap' tides?

34.* Explain by the aid of a sketch-map the course of the tidal wave around the British Islands.

35. What changes are usually observed as a comet approaches and recedes from the sun?

36.* State what you know concerning the connection between comets and meteorites.

37. Describe the physical appearance and structure of meteorites.

38.* Compare the composition of meteorites with that of the earth's crust.

39. Name the minerals peculiar to meteorites and give their chemical composition.

40.* How does mean solar time differ from the time shown by a sun-dial, and how is it regulated?

41.* What is meant by the equation of time, and how is it arrived at?

42.* What is the cause, and what the result, of the *precession of the equinoxes*?

43.* State what you know about nutation.

44. The mean right ascension of Sirius on Jan. 1, 1847, was 6 h. 38 m. 25 s., and on Jan. 1, 1877, 6 h. 39 m. 44 s. Explain the cause of this alteration.

45. Explain 'sidereal year,' 'tropical year,' and 'anomalistic year,' and show the relation that exists between these different kinds of years.

46. Prove that the latitude of an observer is equal to the altitude of the celestial pole, or the declination of the zenith.

47.* How is the longitude of a place on land determined astronomically?

48.* What are the methods generally adopted in measuring a base-line for a geodetical survey?

49.* How is the length of a degree on a meridional arc measured?

50.* How has the shape and size of the earth been determined?

51.* How has the density of the earth been determined?

52.* How has the distance of the moon been determined?

53.* State how the distance of the earth from the sun has been determined by observation of Mars at opposition.

54.* Describe the different methods of determining the distance of the sun from the earth.

55. Is it absolutely necessary, as often stated, to find the diameter of the earth in order to find the distance of the sun from the earth?

56.* What is meant by the aberration of light?

57.* How does the constant of aberration enable us to determine the distance of the sun?

58.* How are the distances of the stars determined?

59. How does the law of gravitation enable us to find the mass of the moon, or the mass of the sun?

60.* How has the mass of Jupiter been determined?

61. How may the stars be classified according to temperature?

62.* State what you know about variable stars. What causes of variability have been assigned?

63.* Describe the various forms of nebulæ.

64. Write what you know about the spectra of nebulæ.

65.* What are the chief corrections which it is necessary to apply to the readings of a barometer?

66.* How would you explain the low temperature which prevails in the higher regions of the atmosphere?

67.* Describe the trade winds, and state the causes to which they are due.

68.* Describe the monsoons; stating the periods at which they blow, the countries in which they are felt, and the causes to which they are due.

69.* What are cyclones and anti-cyclones; how are they produced, and why does the wind move in opposite directions?

70. What are the chief causes that give rise to ocean-currents?

71.* Explain the influence of the waters of the ocean in modifying the climate of the adjoining land.

72.* State what you know concerning the distribution of temperature in the waters of the ocean.

73.* How has the vertical distribution of temperature in the waters of the ocean been determined?

74.* What is a dip-circle or dipping-needle? How is it used, and what has it brought us?

75.* Describe the instruments by which the distribution and intensity of terrestrial magnetism have been determined.

76.* How is the intensity of terrestrial magnetism at any place of observation determined?

77.* What facts relating to terrestrial magnetism are given in a magnetic chart of the earth's surface?

78.* How has the rate of increase of temperature in going downwards in the earth's crust been determined; and what are the chief sources of error in such observations?

79. What evidence have we to show that the climate of Britain has undergone great changes?

80. What astronomical causes are at work that may lead to such changes? Are they sufficient?

81.* Describe the chemical and mechanical agencies by which rocks are disintegrated.

82.* Give the names of the minerals which make up the rocks called 'granite,' 'trachyte,' and 'basalt,' and state what you know concerning the chemical composition of these rocks.

83.* Explain the different methods by which limestones have been formed.

84.* State the characters of the chief varieties of lava with which you are acquainted.

85. Give an account of Laplace's hypothesis, stating the grounds on which it was based.

86. What has been learnt from the spectroscopic examination of meteorites?

87. Describe Lockyer's meteoric-nebular hypothesis?

88. What do you know about the spectra of comets?

89. Describe the construction and use of the *alt-azimuth* or the *sextant*.

90. How does the spectroscope enable us to measure the rate of motion in the gas-streams of the sun?

91. Which of the heavenly bodies are not self-luminous? How is this fact ascertained?

92. By what methods are the diameters of the sun, moon, and planets, in miles, found?

93. What is known about the origin of dolomite and serpentine?

94. How is the proper motion of the stars detected (i.) by the telescope, (ii.) by the spectroscope?

EXAMINATION PAPERS SET BY THE SCIENCE AND ART DEPARTMENT.

MAY, 1888.

Second Stage, or Advanced Examination.

INSTRUCTIONS.

You are permitted to attempt only FIVE *of the following questions.*
The value attached to each question is the same.

21. I wish to compare the barometric readings taken at two places; what data with respect to these places will it be necessary for me to have, and why?

22. Explain why the influence of the moon is greater than that of the sun in causing tides.

23. What is 'ground-ice,' and under what condition is it formed?
24. How has the mass of Jupiter been determined?
25. What are the organisms that have the power of separating silica from sea-water, and what is the nature of the deposits formed by these organisms?
26. State what you know about variable stars.
27. State what you know concerning the mode of formation of different kinds of volcanic cones.
28. Describe the various forms of nebulæ.

Third Stage, or Honours Examination.

INSTRUCTIONS.

You are permitted to attempt all, or any, of the questions.
The value attached to each question is the same.

41. Give an account of the phenomena observed on the solar surface during a sun-spot period.
42. Describe a magnetic observatory.
43. Give an account of the metallic meteorites. What terrestrial rocks exhibit any resemblance to them?
44. Describe the characters of the cyclonic and anti-cylonic movements of the atmosphere, north and south of the equator respectively.
45. Give an account of the results which have been obtained by recent researches in connection with *one* of the following subjects:—

(*a*) The spectra of stars and nebulæ
(*b*) The origin of serpentines.

TRAINING COLLEGE EXAMINATION, 1888.

Second Stage, or Advanced Examination.

INSTRUCTIONS.

You are permitted to attempt only FIVE *of the following questions.*
The value attached to each question is the same.

1. How is the transit-circle used, and what information does it furnish?
2. If we ascend to the height of three and a half miles in a balloon with a barometer and thermometer, what changes shall we note in the readings of the instruments during the ascent? State what you know concerning the causes of these changes.
3. Describe the planet Saturn.
4. What meteorological conditions are most favourable for the formation of dew, and why?
5. How is the precession of the equinoxes caused?
6. State what you know about the Gulf Stream and its origin.
7. What are comets?
8. What are the chief grounds for believing that water plays an important part in volcanic eruptions?

Honours Examination.

INSTRUCTIONS.

You are permitted to attempt FOUR *of the questions.*
The value attached to each question is the same.

1. Describe the surface of the sun.
2. Describe the distribution of different varieties of coral-reefs on the earth's surface.
3. How is stellar parallax measured?
4. What are the chief minerals which have been found both in terrestrial rocks and in meteorites, and what are the substances which have been found only in the latter?
5. State the spectroscopic classification of the heavenly bodies.
6. Give an account of the differences in composition of sea-water collected in different areas and at varying depths.

May 1889.

Second Stage, or Advanced Examination.

INSTRUCTIONS.

You are permitted to attempt only FIVE *questions.*
The value attached to each question is the same.

21. What is meant by the proper motions of the stars, and how has the distance of certain stars been ascertained?

22. Explain the precautions necessary in determining the temperature of the earth's crust at different depths—

(*a*) In mines and tunnels.
(*b*) In wells and bore-holes.

23. What is meant by magnetic declination and inclination respectively, and how may each be observed?

24. What are isotherms? What are the data required for drawing them upon a globe? Why do isotherms vary from parallels of latitude?

25. The sun's attraction at the earth's surface is much greater than that of the moon, yet the moon is the more important agent in producing tides. State the exact reason of this.

26. Explain the ordinary method used in determining the 'mean annual rainfall' of a place, and state the chief sources of error in the observations which have to be made.

27. State what you know about nebulæ.

28. What do you know about the foraminifera and the part which they play in building up rock-masses.

Honours Examination.

INSTRUCTIONS.

You are permitted to attempt all, or any, of the questions.
The value attached to each question is the same.

41. How has the mass of the moon been determined from lunisolar precession?

42. Describe some recent results obtained by means of long-exposure photographs of the heavenly bodies.

43. What are geo-isotherms? State what you know concerning the position of those within the earth's crust.

44. Describe the different methods which have been devised for recording the duration and intensity of sunshine on different days.

45. Give an account of the results which have been obtained by recent researches in connection with one of the following subjects:—

(*a*) Laplace's hypothesis of the origin of the sun and planets.
(*b*) The transmission of great air-waves during volcanic outbursts of exceptional violence.

TRAINING COLLEGE EXAMINATION, 1889.

Second Stage, or Advanced Examination.

INSTRUCTIONS.

You are permitted to attempt only FIVE *of the following questions.*
The value attached to each question is the same.

1. How does a transit instrument enable us to keep a mean-time clock right?

2. What do you know concerning the proportion of water present in the atmosphere, the state in which it exists, and the sources from which it is derived?

3. Why does the spectroscope enable us to view the solar prominences without an eclipse?

4. What do you know concerning the temperature and density of the deeper parts of the oceans?

5. Describe the observations necessary to measure an arc of meridian.

6. What are the nature and origin of the electrical effects that accompany a volcanic eruption?

7. State the magnetic elements, and how two of them are obtained.

8. Compare the action of rain and rivers in producing the features of the earth's surface.

Honours Examination.

INSTRUCTIONS.

You are permitted to attempt FOUR *of the questions.*

The value attached to each question is the same.

1. What are the views held as to the origin of comets' tails?

2. Describe the mode of occurrence of metallic iron in meteorites and in certain rocks belonging to the earth's crust.

3. Describe the spectra of the nebulæ.

4. Give an account of the results obtained by the most recent attempts to determine the rate of increase in temperature as we descend in the earth s crust.

5. Give an account of recent researches in connection with one o the two following subjects:—

(*a*) The cause of variability in stars.

(*b*) The origin of dew.

May 1890.

Second Stage or Advanced Examination.

INSTRUCTIONS.

You are permitted to attempt only FIVE *questions.*

The value attached to each question is the same.

21. What are the facts which lead us to suppose that the moon has no atmosphere?

22. What is lava? In what forms does it appear at the earth's surface? State what you know concerning the composition and different varieties of lava.

23. State what you know about the 'Aberration of Light.'

24. How has the temperature of the deeper parts of the ocean been determined? State what you know of the temperature of the ocean at different depths.

25. How is a measured 'base-line' used in determining the length of an arc of meridian?

26. What do you learn from the statement that on one day the barometer indicated 29 inches and on another day 28 inches? State what you know of the causes that produce this difference.

27. What observations are necessary to determine the 'magnetic elements' in any locality?

28. Describe the chemical changes which take place in the conversion of vegetable tissues into coal.

Honours Examination.

INSTRUCTIONS.

You are permitted to attempt all, or any of, the questions.
The value attached to each question is the same.

41. How have stars been classified in relation to their spectra?

42. What is a comet, and what are the changes produced in it during its journey round the sun?

43. What is known concerning the differences of properties of fresh water and the salt waters of the ocean?

44. Describe the chief methods employed for determining the heights of mountains.

45. Give an account of the results which have been obtained by recent researches in connection with *one* of the following subjects :—

(*a*) The distances of the stars.
(*b*) The origin of fogs and mists.

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